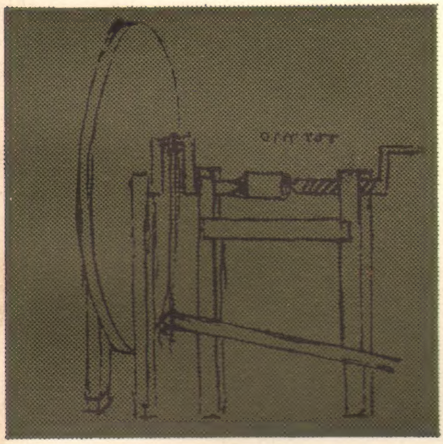
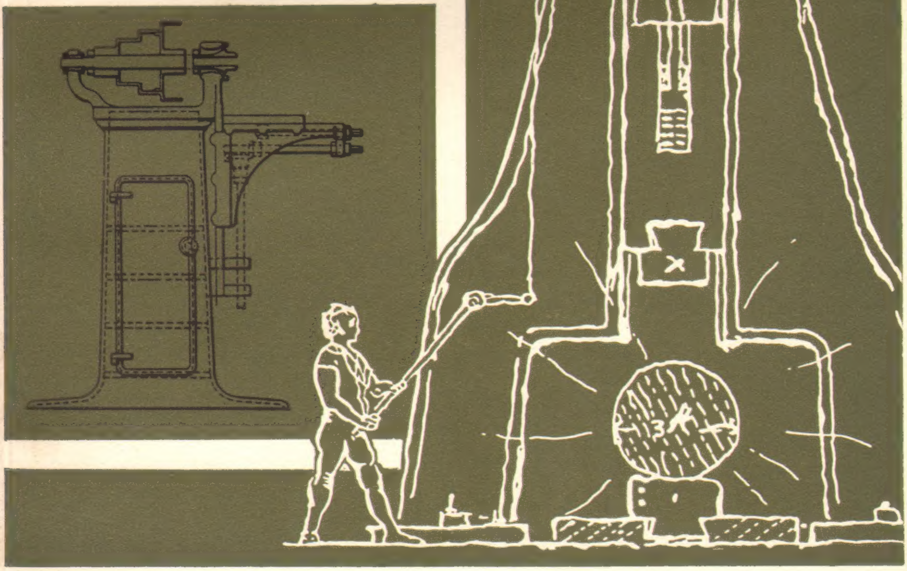
MACHINE TOOLS

Catalogue of the collection

Science Museum





Cover illustrations:

Treadle lathe, c.1500. From a drawing by Leonardo da Vinci
Steam hammer, 1839. From a drawing by James Nasmyth
Universal milling machine, 1861. From a drawing by Joseph R. Brown

Science Museum

Catalogue of Exhibits
with Historical
Introduction

The Machine Tool Collection

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Preface

In 1857 James Nasmyth presented a working model of his steam hammer to the new South Kensington Museum, part of which later became the Science Museum, and thus initiated the Machine Tool Collection, which is now unrivalled in this subject for the historic value of its contents. The growth of the Collection may be seen by inspection of the inventory numbers, on pages 101–108, the first component of which is the year when the object was acquired. The previous edition of the catalogue in 1920 listed only 38 per cent of the objects now on inventory.

This catalogue includes all the machine tools and associated objects, whether exhibited or not, which were on inventory in May, 1964.

Objects in reserve can usually be seen by arrangement, except in the case of large machines which have been dismantled for storage. The hand tools are exhibited in the same gallery, but are not listed here.

The Catalogue begins with the processes in which metal is shaped by being made to flow, such as by hammering, rolling, pressing, and shearing. Then it deals with the basic methods of working by cutting away surplus material: by turning, drilling, boring, planing, shaping, milling, screw cutting, gear cutting, and sawing. Sections dealing with copying machines, manufacturing machines for making specific products, and with portraits follow; and the catalogue concludes with a miscellaneous section for machines otherwise unclassified.

Working in metal and in wood have traditionally been separate crafts; consequently wood-working machines and metal-working machine tools are usually considered apart. In this catalogue, however, machines functioning in a similar manner are treated together irrespective of the material for which they were designed, but the entries applying to wood-working machines may be picked out by referring to the index.

Much of the Collection has been photographed and prints may be ordered from the Publications Section of the Museum, quoting the photograph negative numbers listed on pages 101–108.

The following introduction provides a survey of machine-tool history with particular reference to the Science Museum Collection, and draws attention to the more significant items by quoting their catalogue numbers (bold figures) or plate numbers (italics). The dates of birth and death of inventors mentioned in the text are given in the index.

Acknowledgement is due to the author's predecessors who wrote the earlier catalogues and explanatory labels. These have been freely used in preparing many of the catalogue entries.

Introduction

A machine tool is a machine designed to cut or shape metal or other substance. The essence of a machine tool is that there is built into it some element of the skill which would be necessary to carry out a similar operation manually with the aid of a hand tool. Thus in a lathe the work, as the piece being machined is often designated, is rotated about a fixed axis and the tool may be controlled by hand; or, in a more advanced lathe the motion of the tool holder also is guided by plane surfaces, so that the accuracy which was originally put into the manufacture of the lathe bearings, spindle and guide surfaces is reproduced in the product of the machine.

In general, as the machine is rendered more automatic, the skill required to operate it is diminished. Thus, hand-turning a wooden bowl is a task for a craftsman, but in a screw machine the various tools are applied automatically to bar stock, and the screws or other products, which result from several operations, continue to flow from the machine as long as stock is supplied to it. Skill has been applied only in the original design and manufacture and in the setting-up, and the machine should then function without skilled attention.

Also a machine tool may be made to do work with an accuracy unattainable by hand methods. Furthermore the application of power makes it possible to machine objects of great size, beyond the capacity of a man unaided, and thus to build massive machines and the engines to drive them. By reason of the high speed of working with power-driven machine tools and the economic utilisation of skill, manufacturing processes which would not otherwise be commercially practicable can be successfully undertaken. These properties have made machine tools fundamental to industrial civilisation.

The most ancient machine tool was the lathe. The earliest certain evidence of turning is an Etruscan wooden bowl of c.700 BC unless it is accepted that a bowl of c.1200 BC found in Mycenae was in fact turned. The legs of ancient Egyptian furniture which appear to have been turned are found on examination to have been only carved and polished. The earliest representation of a lathe is, however, in a late Egyptian tomb of the third century BC. In that lathe the workpiece was rotated by a cord which passed round it and was pulled to and fro by an assistant, as in the Chinese lathe (**52**). The cord could be managed by the turner himself if the ends were tied to a bowed piece of wood. The bow lathe has survived in the near east from ancient times (**51**, *6*) and also in the equipment of the watch maker (**67**).

The turner, working with a bow lathe, had to use one hand to push the bow; but the mediaeval invention of the pole lathe freed both hands for controlling the tool. In the pole lathe the cord was driven down by a treadle and returned by a spring pole (**54,** *9*). The first illustration of this is to be found in a thirteenth century window in Chartres cathedral.

So far the workpiece had been rotated back and forth and the tool had cut intermittently, but in the next stage of evolution continuous rotation was obtained: either by using a treadle and fly wheel, as was first depicted by Leonardo da Vinci (cover); or with the help of an assistant, as in the great wheel lathe (**56,** *7*), which was in use by the sixteenth century.

In all these lathes while the rotation of the work was provided mechanically, the turner had to use his skill to hold and guide the tool. The great advance of providing a means for holding and advancing the cutting tool, a principle applicable to other machine tools, was the invention of the slide-rest, which appears for the first time in a drawing in the Mediaeval Housebook, a German manuscript, dating from c.1480.

Three other machine tools were introduced in the Middle Ages: the power saw, the boring machine, and the water-driven hammer. A reciprocating water-power saw with return provided by spring pole was drawn by Villard de Honnecourt in c.1250. A water-powered machine for boring out logs to make water pipes was illustrated in c.1430 and similar machines for boring out cannon were described in the sixteenth century (**136**). Water-driven hammers were mentioned in the eleventh century and continued in use until they were displaced by the steam hammer in the mid-nineteenth century, (*1* to *3*).

At the end of this period the extraordinary genius of Leonardo da Vinci manifested itself in machine-tool invention as in so many other fields, but his failure to publish prevented his ideas from becoming generally known, so that he was without influence on the course of development. In his manuscripts are to be found drawings of machines for boring (**136**), grinding, wood-planing, rolling, sawing, screw-cutting (**124**), file-cutting (**236**), and of various chucks and a tool for broaching. Some of his designs anticipate those of two or more centuries later and may therefore be regarded provisionally in the absence of further evidence as original. Others presumably record the practice of his own time.

By 1770 the machine tools at the disposal of industry had scarcely advanced beyond those available in the Middle Ages. Thus Matthew Boulton, who employed between seven and eight hundred workers in his Soho factory at Birmingham, wrote at that time: 'I have two water mills employed in rolling, pollishing, grinding and turning various sorts of laths'. In some specialised fields, however, certain advances had been made. Rolling and slitting mills were used in coin manufacture from the sixteenth century and Cellini described a screw press for coining. The balance press or fly press was in use for coining by the seventeenth century (*5*). Christopher Polhem in Sweden in 1745 introduced grooved rolls for rolling sheet iron in all kinds of section. For turning plain rolls Polhem described a lathe in which the cutting tool mounted in a slide-rest was traversed by a lead-screw.

Turning had been a leisure occupation in the highest ranks of society since the time of the Emperor Maximilian. An elaborately decorated lathe presented to him in 1500 still exists. Tsar Peter the Great of Russia possessed several lathes for rose turning and for copying medallions and ornamented cylinders which were specially made for his own use in about 1720 and which are now to be seen in the State Hermitage Museum in Leningrad. The interest of the amateurs led to the development of the art of ornamental turning, for which were required several ingenious lathe accessories, such as the oval chuck, for producing complicated shapes and patterns. These rose engines were finely made and sometimes, especially in the eighteenth century, were richly decorated (*8*). The tool was mechanically controlled by means of the slide-rest, a practice which was later taken over in the design of the industrial lathe; but ornamentation was produced by rocking or sliding the lathe spindle. Patterns were traced by the oscillation of a rosette against a rubber and screws were reproduced by engaging one of the master threads on the mandrel by wedging up a bearing having a threaded surface of the same pitch (*15*). This caused the workpiece to traverse and a chasing tool held against it reproduced the thread. Screws were originated by the laborious process of chiselling and filing the threads on the surface of a cylinder which had been marked out. One such procedure for both external and internal threads had been known since Roman times.

For clock-making, also, some special machine tools had been devised. Screw-cutting machines were invented in the eighteenth century for cutting fusees; the later is a clock-part in the shape of a hyperboloid on which a screw-like groove is cut (*20, 21*). It was also necessary to make a variety of gear wheels. The form of tooth was not important, as clock wheels turn slowly and transmit little power, but accurate indexing was essential. The earliest surviving wheel-cutting machine dates from the late seventeenth century, (*18*), but there is evidence that such machines existed as early as 1540.

The great impetus to machine-tool invention came from the industrial revolution. The steam engine, textile and other manufacturing machinery, and later the railway, required machine tools for their manufacture; and this demand stimulated progress.

One of the factors that held up the development of the steam engine was the difficulty in boring out a cylinder with sufficient accuracy. Smeaton in 1769 built a boring machine (**138**) for use in boring the cylinders of Newcomen engines, but it was not possible to achieve with it the accurate fitting of piston in cylinder demanded by James Watt for his improved engine. Fortunately by the time Watt had patented his separate condenser and had overcome financial difficulties by his partnership with Boulton, this constructional problem was solved by the iron master John Wilkinson. He had previously built a cannon-boring machine and in 1775 he built the first really large power-driven machine tool, the cylinder-boring machine, on which the engine cylinders were bored until 1800 when Watt's patent expired and the partnership terminated. Wilkinson's boring machine, by making possible Watt's rotative engine and hence the power-driven factory, thus inaugurated the machine age, (*22*, **139, 140**).

The problem of manufacturing economically and with adequate precision the complicated but very successful lock invented by Joseph Bramah in 1784 led to the construction of a number of new machines, (**211–215**), among them the spring-winding machine, (*29*), which resembles a screw-cutting lathe; and to the very early use of milling cutters. According to John Farey, who had known Bramah, writing in 1849: 'The secret workshops ... contained several curious machines, for forming parts of the locks, with a systematic perfection for workmanship, which was at that time unknown in similar mechanical arts. These machines had been constructed by the late Mr Maudslay, with his own hands, while he was Mr Bramah's chief workman ...' Thus Bramah's factory saw the first employment in machine-tool building of Henry Maudslay, who figured most significantly in the history of machine tools. In 1797 Maudslay left Bramah and set up his own business. In 1804 he was joined by Joshua Field, a draughtsman from Portsmouth dockyard, and the firm continued in being until the end of the century under the well-known name of Maudslay, Sons, & Field, (*4*). The outstanding features of Maudslay's engineering practice were: the production of accurate plane surfaces, the adoption of all-metal construction, the use of the slide-rest, the production of accurate screw threads, and the standardisation of the pitches and diameters of screws used in his workshop.

The screw is an essential element of machine tool and instrument construction. Screws are used for the setting and adjustment of the movable parts of machine tools and for bringing about the controlled motions of the parts which bring the cutting tool and the work into contact. The screw is the essential component of the micrometer, one of which Maudslay made accurate to 0.0001 in for use as his workshop standard. He explored the possibilities of screw origination, (**125**), and successfully introduced into industrial practice the screw-cutting lathe embodying slide-rest, lead-screw, and change-gears, (*10*). He was not original in this, for a form of screw-cutting machine goes back to Leonardo da Vinci, (**124**), to Besson, and to the makers of fusee engines; and similar lathes were built by his contemporaries Senot, and David Wilkinson; but Maudslay's position in machine-tool engineering made his the significant influence. Except for clockmakers' tools, which were small, and the costly equipment of the ornamental turners, machine tools up to Maudslay's time, including those he made for Bramah, had had wooden frames. The use of metal throughout in the construction of machine tools began with Maudslay. It made for accuracy by improving rigidity and by making possible the production of plane guiding surfaces. The relative motion of the parts of a machine tool in a straight line results from the control brought about by intersecting plane surfaces and the accuracy of the tool depends on the ability to make true planes. According to Nasmyth: 'The importance of having such standard planes caused him (Maudslay) to have many of them placed on the benches beside his workmen, by the means of which they might at once conveniently test their work. Three of each were made at a time, so that by the mutual rubbing of each on each the projecting surfaces were effaced. When the surfaces approached very near to the true plane, the still projecting minute points were carefully reduced by hard steel scrapers, until at last the standard plane surface was secured.' The reason for making three surfaces coincide is that, with two only, one might be convex and the other concave, but if a third surface can be made to coincide with the first two, all three must be plane.

From 1802 to 1807 Maudslay was engaged in building the Portsmouth block-making machinery. This was the first large scale mass-production plant to use machine tools, (**216–224**, *30, 31*). A well planned series of machines replaced production by skilled craftsmen with great saving in cost. So well were the machines designed and built that several of them continued in use for nearly 150 years. The mortising machine was the first of its kind and gave rise to the slotting machine, (**159**), which was introduced by Roberts in 1830 for cutting keyways in wheels. The Portsmouth block-making machinery is the subject of a Science Museum Monograph, to which the reader is referred for a full account. It is probable that the characteristically elegant appearance of Maudslay's later work, (*12*), derived from his engagement in this project and from his association with the designer of the machinery, Marc Isambard Brunel.

Maudslay's influence was extensive and important, for he employed several men, who later achieved distinction, including Joseph Clement, Richard Roberts, James Nasmyth, and Joseph Whitworth. Roberts had a workshop in which he made parts for textile machines and between 1825 and 1830 invented the self-acting spinning mule. In 1817 he built the first back-geared lathe, (*11*), which gave the possibility of a wide range of spindle speeds. The lathe has a long lead-screw, provided not for screw cutting but for the ordinary traversing feed of the carriage, and a means of automatically disengaging the feed when the carriage reaches a preset stop. He also invented a plate-punching machine which was used in the construction of the Britannia tubular bridge. His planing machine, (*25*), built in 1817, may be the first and is certainly the oldest now in existence. The machinery built by Roberts already had a functional appearance and looked forward to that of Whitworth. Brunel's and Maudslay's machinery by contrast had a style of framing that derived from classical architecture. Nasmyth's drilling machine, (*13*), is a good but late example of this style.

Speaking in 1856, Whitworth said: 'Thirty years ago, the cost of labour for making a surface of cast iron true, by chipping and filing by the hand, was twelve shillings per square foot; the same work is now done by the planing machine at a cost for labour of less than one penny per square foot, and this, as you know, is one of the most important operations in mechanics. It is, therefore, well adapted to illustrate what our progress has been.' The persistence of the beam-type of steam engine has been explained by its having few flat surfaces which needed skilled labour to finish before the introduction of the planer.

Roberts has already been mentioned in this connection, but the invention of the planing machine has also been attributed to Matthew Murray, a builder of steam engines and textile machinery. He kept it secret in a locked room and used it for planing D-valve surfaces. James Fox of Derby, a manufacturer of lathes and textile machinery, was reported to have built a planer in 1814. Clement in 1825 built a planer which for ten years was the only machine capable of taking large work up to 6 ft square. He charged 18*s* a square foot and the machine was then his chief source of income. The table ran on rollers and the machine was bedded on a massive masonry foundation. It was hand driven and had two cutters, one for each direction of travel of the bed.

Whitworth's planer (**156**, *26*), patented in 1835 was power-driven and self-acting. It has a reversing cutter, but by 1860 this device had become unusual and the uni-directional cutter combined with a quick-return motion of the table was employed.

The early machine-tool makers built them primarily for use in their own workshops in order to be able to make other machines. The building of machine tools for sale to other engineering firms was, however, an activity that increased steadily in the first half of the nineteenth century. The Soho Foundry of Boulton and Watt made machine tools for their own use. After consideration had been given to a vertical cylinder-boring machine a horizontal machine was eventually designed by Murdock in 1798 and first used to bore a 64 in cylinder. A list of tools at Soho in 1801 mentions three drilling machines, a lapping machine, and ten lathes. Some of their larger machines such as the wall planing machine were built into the structure of the premises. Another example of such treatment is the drilling and slotting machine, (**143**), erected in one of Strutt's mills.

Simon Goodrich, (**237**), recorded in 1806 discussing with an agent the purchase of machines which were to be exported to Russia. These included: 'a Complete Boring machine for Boreing Cylinders from the same Patterns as Murray's and Woods made by them, a most excellent Machine. A Machine for cutting screws on bolts and a Six Horse Movable Steam Engine all by Murray & Wood very good and cheap—From Fox's of Derby . . . a Large Boring Turning and Screw cutting Lathe—a Machine for Cutting and Dividing all sorts of Large Wheels—a slide lathe for turning and Screw Cutting.' A price list sent by Fox to Goodrich in 1829 listed planers in five sizes and lathes in seven sizes. A workshop fitted out with machine tools by Fox in 1826 at Sielpia Wielka, in Poland, is preserved as a museum.

Of the 54 machine tools described by Buchanan in 1841, 21 were by Nasmyth. While still working for Maudslay he designed a milling machine for cutting the sides of hexagonal nuts. In 1836 Nasmyth invented the shaping machine, (*24*), for planing small surfaces, cutting key-ways, and generally for producing surfaces formed of straight-line elements. The performance of the shaper was later improved by the addition of Whitworth's quick-return motion. Nasmyth's most famous invention was the steam hammer, (*1*), devised in 1839 in response to a request from the designer of the engines of the steamer Great Britain, who proposed a shaft 30 inches in diameter, which was beyond the forging capacity of the time. The steam hammer not only greatly increased the size of forging possible, but by contrast to the trip hammer it delivered a controlled blow. In the words of the catalogue of the Great Exhibition of 1851 : 'This steam hammer is capable of adjustment of power in a degree highly remarkable. While it is possible to obtain enormous impulsive force by its means, it can be so graduated as to descend with power only sufficient to break an egg shell.'

At the 1851 Exhibition Whitworth was the leading machine-tool maker. Twenty other firms exhibited one, two, or even three machine tools, but

Whitworth had 23 exhibits: machines for turning, planing, shaping, slotting, drilling, punching, shearing, nut-shaping, screwing, wheel-cutting, and dividing; screwing apparatus, a measuring machine, and sets of gauges. At the Exhibition in 1862 Whitworth was still the leading manufacturer among the 60 firms that exhibited and his exhibits occupied a quarter of the area allotted to machine tools.

Whitworth, after working for Maudslay and Clement, opened a workshop in Manchester in 1833 and displayed the sign 'Joseph Whitworth, Tool Maker from London'. His outstanding contribution to lathe design was the hollow-box type of bed, which made the machine much more rigid, weight for weight, than the earlier triangular-bar construction, and protected the lead-screw from damage and dirt, (*14*). He also applied the split-nut principle for engaging the lead-screw to make the saddle traverse. In 1839 he patented a self-acting feed motion for the drilling machine, (**146**). Whitworth paid great attention to the preparation of true plane surfaces in machine-tool construction, to accurate measurement, and to the standardisation of screw threads.

The machinery and equipment available to an engineering workshop by the middle of the nineteenth century is well shown in a contemporary model, (*16*), of which the most striking feature is the overhead shafting and the forest of belts necessary to transmit power from the steam engine at one end of the building to each of the many machine tools.

In addition to the basic machine tools already mentioned there had been some development in tools designed for special purposes. Gear-cutting machines of industrial size were built by James White, Fox, Bodmer, Whitworth, Saxton, and others. Machines also existed for reproducing irregular forms. In these the cutting tool was linked with a tracer which was made to go over every point of the object to be copied. From the medallion lathes of the eighteenth century, (**202**), were derived the engraving machines used at the Royal Mint, (*17*, **207, 208**). James Watt in his retirement extended the principle of this type of machine in such a way that it was possible to copy objects in the round, (**203, 204**). Thomas Blanchard of Worcester, Massachusetts, invented a copying lathe in 1818 for making gunstocks on an industrial scale.

It will have been observed that the great advance in machine tools in the last quarter of the eighteenth century and the first half of the nineteenth century took place in England. The general demand for machinery, the stimulus of contact and competition, made England the centre of machine-tool development and the country in which those with the necessary ability could expect to make a career. Thus Brunel was an immigrant from France via America, Bodmer was a Swiss, and Nasmyth came from Scotland.

Towards the end of this period, however, leadership had moved to the United States. The scarcity and cost of skilled labour in America encouraged the adoption of labour-saving devices and mass-production methods. There at about this time the turret lathe appeared, in which several tools were mounted in a turret which could be revolved. The turret was advanced on a slide to bring each tool successively into contact with the work, so that several operations could be performed with a single setting, (**85**). In 1873 C. M. Spencer made the lathe fully automatic. Bar stock was fed through the chuck and converted into screws or other small parts. The stock-feed, the chuck collet, and the tool motions were all actuated by adjustable cams fitted on cam cylinders, (**86, 129**). Such machines are called automatic screw machines. In 1895 E. C. Henn and R. Hakewessell devised the multi-spindle automatic, in which up to eight spindles—originally four—operate simultaneously, all the tools act at once, and a piece is completed each time the tools are withdrawn and the spindles indexed.

Rotary cutters were used first for cutting clock-wheels and had been used for special purposes by, among others, Bramah, Brunel, and Nasmyth; but the difficulty of making the cutters and keeping them sharp retarded the general use of the milling process in spite of its advantages. These are the possibilities of obtaining special shapes in a single operation by the use of formed cutters and the high cutting speeds which a multi-toothed cutter can give without overheating. The milling machine became an ordinary workshop tool in common use with the introduction in New England of F. W. Howe's plain milling machine in 1848 and the similar Lincoln miller in 1855.

The milling machine took on its present appearance with the invention in 1862 by Joseph Brown of the universal milling machine, (*28*). The provision for the rotation of the workpiece in the requisite relationship to the traversing motion of the table enabled twist drills and spiral gears to be made. Brown's invention in 1864 of a formed cutter which could be sharpened by grinding without changing its shape greatly facilitated the adoption of the milling machine, (**178**).

The interchangeable system of manufacture—that is the system of manufacturing objects in which the specimens of any given part are so alike that the product may be assembled from any set of component parts taken at random—was first developed for the manufacture of fire arms and is believed to have been first practised in the eighteenth century by a French gunsmith named Le Blanc. The military advantage of having interchangeable gun parts is obvious, but the system is also economical because skilled fitting can be replaced by unskilled assembly. This presupposes that the manufacture is on such a scale as to warrant the use of special machines to carry out some of the operations, the provision of jigs to adapt each machine tool to its job, and the use of gauges for checking that the product is within the required tolerances at many stages in the manufacture.

Besides its early use for the production of firearms the system was used at an early date for the manufacture of gear pumps and later in the manufacture of sewing machines, typewriters, and motor cars.

Following a report by Whitworth of a tour which he made in 1853 of the manufacturing districts in the United States, the British Government decided to establish a factory at Enfield for the manufacture of small arms on the 'American System'. Machinery was purchased by a committee sent to the United States and used to manufacture 1,200 rifles per week in 719 operations. It was with the importation of the Enfield machinery that the milling machine was introduced to England. The specialised lock-recessing machine, (*32*), survives from this plant, which was then possibly the most advanced in the world.

Various special grinding machines had been built from about 1830 onwards, but precision grinding as a general workshop process only became important with the invention of Brown and Sharpe's universal grinding machine in 1876, (**187**), which was originally built to grind parts for the Willcox and Gibbs sewing machines.

Another important step was taken by E. G. Acheson who discovered in 1891 how to make a synthetic abrasive from which grinding wheels of uniform and controllable characteristics could be manufactured. This was carborundum or silicon carbide, made by heating clay and carbon together in an electric furnace.

Grinding has the advantage that machining can take place after hardening. In the twentieth century grinding became a process for high speed and high precision production. Centreless grinding in particular, invented in 1915, made for very high production rates at low cost.

New materials for cutting tools increased cutting rates from 40 feet per minute with carbon steel in 1850 to 120 feet per minute in 1900 with high-speed steel containing tungsten, chromium, and vanadium. In the 1920s a further advance came with the use of the very hard tungsten carbide for the cutting tips of tools, (**123**).

The new steels and the use of grinding machinery made it practicable to manufacture the tools of intricate shape required for broaching, (**245**), so that at the turn of the century a technique which goes back to Leonardo da Vinci and Polhem became a valuable production method.

Numerous methods of cutting gears adequate to transmit power were invented in the nineteenth century. These included the use of formed milling cutters, (**175–179**), and hobs, (**183**), and machines for shaping bevel gears, (*19*, **180–182**).

The newest of the standard machine tools is the jig-boring machine. It is used for locating and boring holes with high precision in the jigs, fixtures and dies used in mass manufacturing, and is built with an accuracy which demands housing in an air-conditioned room at constant temperature. The first machine of industrial size, built in Switzerland in 1921, (*23*), derived from a pointing machine designed there in 1912 for use in watch making. Another type of jig-boring machine was brought out in America in 1917.

By the end of the nineteenth century the availability of electric power made electric welding practicable, (**48**), but its most obvious and far reaching effect in machine-tool engineering was to bring about the gradual disappearance of centralised drive by belt and pulley from a steam engine. Machine tools began to be fitted each with its own motor, with the great advantages of increased safety and flexibility and reduction in transmission loss and noise.

An exhibition model was designed in 1963 to show the general appearance of an engineering workshop a century after that illustrated on plate *16*. It contrasts with the earlier model in several respects: 1. individual drive—each machine with a built-in motor and all gearing encased, 2. a large group of grinding machines in a separate air-conditioned room,

3. jig-boring machines in a room maintained at constant temperature,
4. a larger and diversified group of milling machines.

The most remarkable machine to be seen in the modern motor-car factory is the transfer machine. This is a super machine consisting essentially of a group of automatic machine-tools synchronised in their operation and linked in sequence by a mechanical handling system. A model, which in 1964 was being constructed for the Collection, shows a 14-station transfer machine for machining cylinder heads. The block of metal is transferred at the conclusion of each cycle from one station to the next, where the required process, such as face milling, drilling, or tapping is performed. One of the stations is used for turning the workpiece through 90° so that operations can be carried out on a different pair of faces. The part which enters the machine as a casting emerges from it with the machining completed. The first transfer machines were built for the Morris Engine Factory at Coventry in 1923–24. The model represents a machine 60 ft long completed in 1962, but much larger machines have been built. Such machines are integrated with others so that the parts produced are fed into the assembly line at the proper rate and as required for the particular sequence of vehicles on order.

In the mid twentieth century ways of metal-working were introduced which departed radically from traditional methods. In explosive metal-forming sheet metal is forced into a die by the shock wave generated by a chemical explosion, by vapourising a wire electrically, or by electro-magnetic forces. Non-circular holes can be made by cutters vibrating in the manner of a road drill, but at ultra-sonic frequency, (**154**). In electrolytic machining, the metal to be cut away is the anode, the 'cutter' wheel is the cathode, and the fast flowing electrolyte carries away the metal removed. This process, which is the reverse of electro-plating, is very rapid and enables surfaces of intricate shape to be formed. Spark machining removes material by very localised vapourisation and is valuable for cutting extremely hard substances, such as cemented carbide.

The development of automaticity in machine tools transferred more and more of the controlling actions of the craftsman to the mechanism. Thus an automatic lathe will continue to perform all the operations necessary to make the product while there is unused stock in the machine, but skilled re-setting is needed if a different product is required to be made. Such a machine is therefore only economical for quantity production, where the cost of setting-up can be spread out over a large batch. For a short run it is an advantage not to have such a rigid set-up which may also require expensive jigs and fixtures. In the 'numerically controlled' machine-tool the virtues of versatility and automaticity are combined. In this system a lathe, drilling machine, or milling machine is equipped with a tool changer and a means of translating and rotating under power the work relative to the cutter. These motions together with the spindle speed are electronically controlled and actuated by signals given by the presence or absence of holes in certain standard positions on a punched paper tape. A group of holes meaning '1', and no holes meaning '0', can be made to indicate, by a combination of binary and decimal counting, a number of perhaps six digits, which represents an instruction to the machine. Hence the system is known as 'numerical control'. The designer of the part to be machined has to draw up a programme giving the co-ordinates of points, radii, speeds, and tool details, which are then encoded by a tape-punching machine. The tape is threaded in the machine-tool control unit, and the machine then functions as planned.

The principle of controlling a machine by means of a perforated strip of paper is due to Basile Bouchon, a Lyons weaver, who in 1725 invented this method for weaving figured cloth. As applied to machine tools 'tape control' combined with electronic techniques makes possible fully automatic continuous-path machining in accordance with the stored-up programme prepared by the designer.

Catalogue

Hammers

See also **228** & **237**

1 Model of Lift Hammer 1556

Scale 1 : 6

This working model has been reconstructed from illustrations contained in 'De Re Metallica', which was written by Agricola, a German mining engineer, and published in Basle in 1556. It represents a natural stage in the development of the power hammer from the heavy sledge hammer. Power hammers were in use from the twelfth century in the West, but were known in China two millennia ago.

The hammer is lifted by means of wooden cams driven into a built-up drum which is secured to the shaft of a water wheel and bound with iron hoops. The length of the haft has been estimated at 4 ft and it is pivoted on an iron pin supported in a heavy timber framework. On the same scale the weight of the hammerhead would be about 65 lb.

In one of Agricola's drawings there is a suggestion of a spring beam to give added force to the blow, but in the absence of corroborative evidence that such a device was in use at so early a date, it has not been included in the model.

2 Oliver

This oliver or treadle hammer forms part of the equipment of a nailmaker's forge. This example consists of two hammers pivoted between a pair of upright posts. They are each balanced by bent poles as in the pole lathe and operated by separate treadles. The oliver was first described in 1686 in Plot's 'Staffordshire'.

3 Oliver

This treadle hammer forms part of a chain-maker's equipment and is similar to No. 2.

4 Two etchings of Lift Hammers by Noel Spencer

These water-driven hammers are at Wortley Forge, Yorkshire.

5 Hammer Mill

(*See Plate 2*)

This machinery, which is thought to date from the eighteenth century, was removed from Holbeam Mill, near Newton Abbot, Devon, where it was in use until 1942.

The two tilt hammers were operated by a pitchback water wheel, 12 feet in diameter and just visible through the small door, which received water from the River Lemon through an open leat and wooden launder. The axle is a rough-hewn oak trunk, on which are wedged two cast-iron cam-rings, the cams of which raise the hammers by pressing down their iron-shod tails. On disengagement the hammers fall back on the anvils.

This mill was used for the manufacture of thatchers' sickles, hedging hooks and grass sickles; and there is a tradition that in the days of sailing ships fishermens' knives and fishing hooks were made for export to Newfoundland.

The smith is seen at work at the forging hammer while the lighter hammer, used for finishing, is propped up in order to disengage it from the cams. The frequency of the hammer blows was controlled by adjusting the opening of the sluice over the water wheel, which is connected by levers with the linked rods, which end in a perforated plate. This was secured to whichever hammer head was not in use, by a peg. A second water wheel was used to drive the bellows of the forge.

The bevel-gear ring between the cam rings and the water wheel drove a bevel pinion. This gave motion through spur gearing, which is not shown, to a large drum, which was used to drive through belting the wood-turning lathe for making the handles of the tools.

Water-driven hammer mills were widely used from the Middle Ages until the advent of the steam hammer in the mid nineteenth century, but very few of them now survive.

6 Model of pair of Forge Hammers

The model represents a design for a pair of forge hammers driven by two engines side by side. Such a scheme was prepared by Boulton and Watt for John Wilkinson in 1781 for his Ironworks at New Willey, Shropshire, but was not proceeded with because it embodied the crank, and Watt feared litigation with Pickard, who had patented the application of this to engines.

7 Model of combined Lifting and Tilt Hammer

The model shows an arrangement of a lifting hammer and a tilt hammer driven from the same shaft. There are some resemblances between this model and the plant put down by Boulton and Watt for John Wilkinson at Bradley Forge, Staffordshire, in 1783.

A beam engine drives a heavy flywheel on a horizontal shaft with two cam rings. The one with three cams drives a lifting hammer with axis parallel to the shaft and the one with four cams drives a tilt hammer at right angles to the shaft. On the former there is provision above the helve for a spring beam to obtain a heavier blow than would be obtained by gravity alone.

8 Model of Lift and Tilt Hammers 1804

Scale 1 : 12. (*See plate 3*)

The working model shows two hammers which were erected in Portsmouth Dockyard by Simon Goodrich. They were driven direct from the crankshaft of a beam engine, the lift hammer being used for forging iron and steel and the tilt hammer for softer metals.

The front bearing pin of the cam shaft is an extension of a cast-iron cage which slides over the end of the shaft and is secured to it by metal wedges; and the cam ring is mounted on this cage through wedges of oak, which are driven in to form an annular packing.

The cams are replaceable when worn and provision is made for additional cams in the case of the lift hammer.

The bearings of both hammers are adjustable in their brackets for height and distance from the centre line of the shaft and the brackets themselves are made to slide longitudinally in their base plates.

In the model, the surrounding earth has been partly cut away to show the construction of the foundation which is made of timber baulks, bolted or tied together. The base plates for the bearing brackets and anvils are sunk in the foundation and are bolted to it. Some of the floor boards covering the base plates have been omitted.

9 Model of Steam Hammer

Scale 1 : 4. (*See plate 1*)

This is a working model, presented to the Museum in 1857, of the steam hammer invented by Nasmyth about 1839 and patented in 1842. It consists of a base plate with a large central opening through which projects the top of the anvil, so that a blow on the anvil is not transmitted to the base plate. On the plate are secured two standards which form guides for the hammer head or tup, and also support an overhead cylinder, the piston of which is connected with the tup by a piston rod passing through the bottom of the cylinder. Steam is admitted to this cylinder by a stop valve in the form of a slide, and then by a slide valve on the front of the cylinder, which by a hand lever can be moved so as to let steam in below the piston and so raise the heavy tup. When it is lifted to a height proportionate to the energy of the blow required the steam is permitted to escape by the slide valve and the hammer falls upon the forging placed on the anvil. The cylinder is therefore only single acting, but the top is closed and inside is provided at a little distance down with a ring of holes communicating with the exhaust pipe. In this way an air cushion is formed which helps to start the piston downwards when a long stroke is being taken, and also the steam below the piston is permitted to escape when the tup has been lifted as high as it can safely go. Soon after its invention the steam hammer was greatly increased in power by accelerating the fall of the tup by admitting steam above the piston in the down stroke and so changing it into the present double acting steam hammer.

The valve gear for regulating the number and strength of the blows is also arranged for working automatically. This mechanism was invented in 1843 by Robert Wilson, one of Nasmyth's partners. The slide valve of the hammer is connected with a small overhead steam cylinder which always acts in such a way as to let steam below the hammer piston and so keep the hammer head up; but a tappet on the tup, when a certain height has been reached, strikes a lever which reverses the slide valve and so lets the hammer fall. This reversing lever is carried on an adjustable fulcrum so that the reversal can take place at any desired lift of the tup. After reversal a catch retains the valve in this position, but when the blow is struck, a swinging arm on the face of the tup by its momentum strikes an arrangement of levers by which this catch is released, and the valve allowed to return to the position required for commencing the next lift of the hammer. In this way the whole energy of the fall is utilised before the steam is permitted to act again on the upward stroke, irrespective of the thickness of the forging under treatment.

10 Wilson's Self-Acting Valve Gear for the Nasmyth Steam Hammer

Drawing dated 1848.

11 Steam Hammer c.1850

This steam hammer, which stands 10 ft 9 in high, was built by James Nasmyth & Co. It was installed in the Royal Mint until 1933 (*see* **9**).

12 Photograph of the first drawing of the Steam Hammer

This photograph came from James Nasmyth's album and is of an entry in his scheme book. The date of the first sketch is 24th November, 1839. Part of the drawing is reproduced on the cover of this catalogue.

13 Painting of a Steam Hammer at Work

This picture was painted by James Nasmyth. It is initialled J.N. and dated 1871. It is reproduced in Nasmyth's *Autobiography.* 15½ in × 19½ in.

14 Model of Steam Hammer 1905

Scale 1 : 16

This is a double acting hammer of the arrangement patented in 1854 by William Rigby.

The cylinder is bolted to a single standard, thus leaving room for work on three sides. The piston and rod are in one forging and the latter has flats on two sides and a dovetailed end for the attachment of the hammer face. The gland and stuffing box are in halves and the former is of such depth as to render external guides unnecessary. The anvil block is dovetailed, like the hammer face, thus readily allowing changes to be made.

Steam is admitted by a hand-worked piston valve. In addition the upstroke of the piston is automatically controlled by a tappet lever connected with the valve spindle and struck by the hammer head.

The anvil block is a separate solid casting which stands up through a hole in the sole plate; it has a broad base resting on a foundation of 15 in sq timbers. The sole plate is supported separately on similar timbers with the object of lessening vibration.

The piston rod and hammer face weigh 40 cwt; the steam pressure used is about 30 lb/sq in.

15 Model of Power Hammer 1904

Scale 1 : 8.

In this working model, the hammer-head is directly worked by an air cylinder, in which the pressure is being alternately diminished and increased by communication with another cylinder in which a piston is reciprocated by the motive power. By this system of working, which was first patented in 1860 by T. G. Dawes, an elastic, rapid and adjustable blow is obtained with a self-contained machine.

In the arrangement shown the hammer-head is directly connected with a plunger which serves as a single-acting piston and also as its guide, while the upper end of the cylinder in which it works is in communication with another cylinder combined with the main standards and having in it a single-acting trunk piston actuated by a balanced crank on a flywheel shaft, driven by belting from line shafting or an electric motor.

The hammer is stopped or its blow varied by two rotary non-return slide valves in the passage connecting the two cylinders. One valve, actuated by a hand lever, controls the passage from the air cylinder to the valve chamber; the other, which is connected with a treadle, controls the passage from the valve chamber to the hammer cylinder; at the top of the stroke the hammer piston passes over the port of this passage, so as to insure pneumatic cushioning.

When the passage is free, the motion of the hammer follows that of the air piston; the force of the blow can, however, be lessened by slightly covering the port to the hammer cylinder. If the latter is completely covered, the hammer will be lifted to the top of its stroke and will remain there. If it is desired to retain the hammer in an intermediate position, the ports to both cylinders must be covered when that position is reached; but if it is required to use the hammer as a vice, the port to the air cylinder must be covered and the port to the hammer cylinder uncovered. The air cylinder is provided with a safety non-return valve.

These hammers were built in sizes from 1·5 to 10 cwt, that represented being of the smallest size, which had a stroke of 8 in and could deal with a maximum thickness of 2 in; it gave 220 blows per minute and required 3 hp.

16 Model of Steam Hammer 1891

Scale 1 : 12

This working model shows a form of double-acting steam hammer, intended for general smith-work. By the use of an overhanging framing the hammer is rendered accessible for work on three sides, but for the heavier types this form of framing is not adopted.

The cast-iron side frames carry the steam cylinder, and form also the guides for the hammer head, which may be of forged iron or steel. The base plate carries the frames, and through a bored hole in it, passes the turned circular anvil block, which transmits the unabsorbed portion of the blow to the foundations shown below. The equilibrium working valve is of the piston type, with the steam in the middle and the exhaust at each end. A lever for working the valve by hand is carried backwards between the frames, and a swinging lever, actuated by the tup and carried on an adjustable fulcrum for varying the stroke, is arranged to move the valve automatically when rapid or regular blows are desired. Owing to the heavy shocks, the piston is forged solid with the rod, but the hammer and anvil faces are removable.

17 Model of Steam Hammer 1906

Scale 1 : 12

This working model represents a double-acting steam hammer with self-acting gear, made by Messrs Davy Brothers.

The cylinder is mounted on a double frame of the ordinary Nasmyth pattern and the hammer head slides between guides formed on it. Steam is admitted through a sliding regulator valve, and distributed by a piston valve having a third central piston which divides the steam chest into two parts, each with a separate steam inlet controlled by the regulator so that steam may be admitted to the under-side of the piston only.

The self-acting mechanism consists of a bell-crank lever, one arm of which is fitted with a swivel block working in an inclined slot formed in the face of the tup, while the other arm is connected with the piston valve spindle. The bell-crank lever is pivoted on a movable fulcrum, the raising or lowering of which varies the stroke.

The hammer frame is bolted to a base plate resting on concrete piers and having a central opening through which the top of the anvil projects. The anvil block rests on a separate foundation of timber balks, bolted together, with a bed of concrete beneath it.

The cylinder is 12 in diameter, and the weight of hammer head, piston and rod is about 16 cwt.

Rolling Mills

See also **39**

18 Models of Rolling and Slitting Mill and Rolling Mill

Matthew Boulton, at his manufactory at Soho, Birmingham, was engaged, like other makers in the district, in rolling sheet metal, and it is possible that these models were made by James Watt to show the applicability of his rotative engine in 1781 to this duty.

19 Machine for Rolling Window Leading c.1820

This early machine was used for rolling window leading of H section from cast ingots.

Two rollers, geared together, are placed one above the other and are carried in steel bearings in the framework of the machine. They consist of spindles with one simple annular ring upon each, and as they rotate and the ingot moves forward, these rings press into the metal and form the cavities into which the glass is subsequently fitted. The metal displaced is forced outwards against forming plates at either side which determine the thickness of metal and width of strip.

The previous method of producing window leading was by casting and then forming in dies in a hand vice. The modern method of manufacture is by extrusion.

An example of the ingots used in the rolling mill is shown with the finished product and also an ingot in the mill and partly rolled.

20 Model of Tyre Rolling Mill 1850

Scale 1 : 6

This represents a machine constructed about 1850 by W. Melling of Haigh Foundry, for reducing the tyre to exact section and circularity by rolling after welding.

Two rolls of the internal and external profile of the tyre respectively are arranged vertically on a horizontal table provided with slots; the inner roll is driven by bevel gearing and is spur geared with the outer roll, thus only permitting screw adjustment within very narrow limits; different thicknesses of tyre would be accommodated by changing the rolls. To the outer roll are geared two other rolls to give the required bending to the tyre. These also have screw adjustment and to admit of the necessary latitude for different diameters, and to drive in the right direction, an idle wheel kept in gear by links is provided. To keep down the tyre on the table a loose roller, which can be fixed in different positions on a hinged lever, is provided. To the table are bolted loose guide rolls which the tyre touches when the correct diameter is attained; these are set by a trammel (not shown) centred on a pin in the middle of the table.

21 Rolling Mill 1882

(*See plate 4*)

This so-called gauging mill was used in the Mint for rolling silver strip to final gauge. The strip originally 0·080 in was reduced in two passes by 0·008 in. The machine was built by Maudslay, Sons, & Field in 1882. It weights 3 tons and operated at 115 feet per minute.

The lower roll is driven direct and runs in fixed bearings. The upper roll is driven through gearing and its bearings are in slides so that it can be brought nearer the lower roll. The upper bearings are adjusted together by screws rotated by means of worm and worm wheel, so that the rolls can be set at the required distance apart.

22 Model of Tube Rolling Mill

Scale 1 : 15

This type of tube rolling mill was patented in 1885 by Reinhard and Max Mannesmann and subsequently developed by them.

An iron billet at bright red heat is rapidly rotated by a pair of tapered rollers so that a cavity is formed by centrifugal force. The rollers are inclined to the axis of the billet with the result that the latter is also fed forward, and, in consequence, reduced in diameter by the action of the rollers. The billet is also guided and supported by plates above and below and in passing out from the rolls is forced over a removable mandrel, which smooths the interior.

The specimens illustrating Seamless Tube Manufacture are lent by The British Mannesmann Tube Co.

23 Model of a Small Rolling Mill c.1930

Scale 1 : 4

This model represents a mill for rolling ferrous or non-ferrous strip metal The rolls are 8 in diameter by 12 in face.

The phosphor-bronze box journals for the roll spindles are fitted in vertical slots, machined in massive castings. The upper roll is adjusted by an overhead handwheel of large diameter, the adjustments being made against calibrated scales, The electric motor, of 20 hp, drives the shaft of the lower roll through reduction gearing in the first gear casing. A pinion on the shaft, meshing with a similar pinion on an upper shaft, drives the upper roll. Both rolls have the usual flexible coupling pieces between the driving shafts and the roll spindles, to permit of roll movement.

Punching and Shearing Machines

See also **39** & **239**

24 Model of a Punching and Shearing Machine 1804

Scale 1 : 8

This is a working model of an early punching and shearing machine designed by Simon Goodrich for Portsmouth Dockyard.

The punch and the moving shear blade are attached near the fulcrum of a long lever on opposite sides. The lever is raised by means of a hand-turned flywheel and gear train, and allowed to fall back by gravity.

25 Model of a Coining Press 1814

Scale 1 : 8

This is an early type of cutting-out press for coin blanks.

The bolster is mounted on the head of a cast-iron frame and the die is carried in a massive crosshead, with adjusting nuts, which is reciprocated by an eccentric on a driving shaft situated below it. The strip of coin metal is fed in by rolls, geared together and intermittently turned by a ratchet driven by a pin on the driving shaft.

26 Model of a Shearing Machine

Scale 1 : 12

The model shows a type of machine patented in 1843 by G. B. Thorneycroft for shearing large iron plates.

The lower blade is fixed and the upper one slides in guides formed in side standards which also hold the bearings of a horizontal shaft. Three cams on this shaft force the blade downwards and two light eccentrics lift it for the next stroke. The shaft has square ends and was probably driven by a cast-iron breaking-shaft that would fail if the cut attempted were too heavy.

27 Cutting Press 1882

This machine was built in 1882 by Ralph Heaton & Sons for cutting coin blanks up to three at a time. It followed the rolling mill,**21**, in the process of coin manufacture and was succeeded by a coining press.

The ram obtains its reciprocating motion from a metal strap which encircles an eccentrically mounted disc on the driven shaft. A variable throw crank operates a ratchet to drive the feed rollers. The strip passes through guides to position it horizontally, through feed rollers, then through the press and finally through another pair of rollers. The press worked at 175 strokes per minute.

28 Model of a Punching and Shearing Machine 1906

Scale 1 : 8

The two machines for punching and shearing are, as is usual, combined in one framing for convenience in working and to save floor space.

The machine is of the eccentric type. It has a massive cast iron framing with a deep gap at each end to enable the plate to be punched or sheared at a distance from its edge. Overhanging both gaps is a main shaft of large diameter, the speed of which is reduced by spur gearing in the ratio 1 :10.5 from that of the first motion shaft, which carried fast and loose pulleys and a flywheel to provide momentum. Each end of the main shaft is turned down eccentrically and on the pin thus formed is fitted a block which slides in a horizontal slot in an apron situated between adjustable V guides; a reciprocating movement is thus given to the apron. To its lower face is bolted the shear blade or punch.

For punching there is a stop motion, consisting of a cam interposed between the block and the apron, which can be turned by handle. This allows of the exact adjustment of the plate under the punch, the latter coming down to the surface without being forced through. This mechanism is not required in the case of shears. An adjustable hinged forked piece between the punch and its bolster serves to strip the plate off the punch as it rises.

The punch and shears move continuously, but their working periods alternate, so as to lessen the fluctuation in energy absorbed. Simple radial post cranes, each with a trolley for conveniently slinging the heavier pieces, are incorporated with the framing.

29 Model of Punching, Shearing, and Notching Machine 1906

(*Working.*) Scale 1 : 8

This machine resembles the preceding one except that a third tool is combined in the framing and that the construction is of the lever type.

On the main shaft are two cams for each lever which rub on a beam suspended from the end of the lever by tie rods. One end of the lever is centred in the framing and, for punching, the other end presses on a D-shaped punch-block, which slides in a vertical sleeve and is raised by two side levers slotted to allow the stop motion to operate; this consists of a cam interposed between the lever and the punch-block and turned down by a handle. For shearing, the outer end of the lever is inserted in the apron carrying the shear blade.

A connecting block is hung in a space within the notcher apron from an eccentric pin on the end of the shaft. The pressure is thus always exerted centrally. Another block inserted between the former one and the apron provides for the stop motion. The two blocks are slotted and can be moved back by a handle so that one enters the other to the amount of the stroke.

The punch and shears have each a period of rest determined by the cams, which are so timed that their periods of operation and that of the notcher are consecutive.

Jib cranes are incorporated with the framing.

30 'Lightning' Sheet Metal Shear 1924

This small, electrically driven, high-speed shear, patented by Messrs Achard et Cie, of Paris, is designed for the rapid cutting of sheet metal. The shear blades are arranged vertically, the upper blade being rigidly attached to an overhanging arm. The lower blade is given a reciprocating and swivelling motion, similar to the motion of scissor blades, by an eccentric direct-coupled to the shaft of $\frac{1}{4}$ hp motor running at 1,200 rpm. This machine is capable of cutting sheet up to 0·08 in thick at the rate of 13 ft per minute.

31 Model of a Punching and Shearing Machine 1925

This model represents a type of lever punching and shearing machine with side limber punch and two jib cranes, commonly used in shipbuilding yards.

The base consists of a massive iron casting on which are pivoted three heavy levers which operate the various punches and shears. Both the punches have stop motions to permit the plate worked on to be positioned with the punch stationary. In the model a hand wheel is fitted, but in actual practice the drive would be either by belt or electric motor. The machine runs continuously and the motions of the three elements are timed consecutively so as to distribute the load evenly and avoid peak loads occurring simultaneously. The jib cranes facilitate handling of large plates.

32 Nibbling Machine 1929

This machine is essentially a punching machine operating at a high speed. It is intended for cutting thin sheet metal up to 14 gauge at a speed of 60 inches per minute. It is especially adapted for small work such as trimming embossed work, duplicating small parts, template making and stencil or sign cutting.

The punch is $\frac{3}{16}$ in diameter and has an extension in its face which does not rise above the surface of the work and thus prevents the work from being pushed out of place as it is fed forward.

Forging and other Metal-forming processes

33 Model of Spoke Bender 1850

Scale 1 : 6

The sector-spoked wrought-iron wheel, commonly used for the rolling stock of the early railways, was patented by W. Losh in 1830, before which cast-iron centres were generally used. This machine, which was introduced about 1850 by W. Melling of Haigh Foundry, was for economically bending such spokes.

Bars rolled or drawn down by forging so as to leave greater thickness in the middle are bent roughly to shape whilst hot and clamped on a die block secured to the crosshead of a hydraulic ram; as the ram ascends, links pinned to it and hinged to links fixed on the framing close against the sides forming the completed outline. The wheel centre is completed by riveting or welding the adjacent spokes together, casting the nave round their inner ends in a suitable moulding box, and turning up the circumference.

34 Model of Forging Machine 1857

Scale 1 : 4

This is an early example of the type of forging machine patented by W. Ryder in 1841, and used for rapid forging of small pieces.

A number of dies or swages of any desired form are fixed in the machine in pairs, the lower dies being fixed in the framing, with screw adjustments, while the upper ones are moved very rapidly up and down by means of eccentrics on the upper shaft, which is driven at about 600 rpm.

The pairs of dies are generally arranged in a series of varying diameters. One of the lower dies is moved up and down in concert with the upper die, by means of a cam on a short shaft below; these two tools form cutting dies or shears. Such machines forge suitable objects with great rapidity, and of almost standard dimensions; some examples of such forgings are shown.

35 Drop Forging

and one completed forging of fender iron for Ford car mudguards as produced by the Ryder Forging Machine in 1924. (*See* **34**.)

36 Specimens of Dies for Coining 1842

These specimens illustrating the method of preparing dies for medals or coins, were made by William Wyon RA, chief engraver at the Royal Mint. The engraver first produced a steel master die, in intaglio, known as the matrix; this was hardened and used to produce, by pressure, a reversed copy called a punch, the steel being frequently annealed during the process. This punch then served to make any number of working dies, in a similar manner, dates and lettering being put on these by hand. In modern practice the matrix is produced, by pressure, from a master punch made on an engraving machine.

37 Medal Press 1862

(*See plate 5*)

This very large fly-press for coining is that built by James Watt & Co for the International Exhibition of 1862. The screw is 6 inches in diameter with three threads of 5½ in pitch. The double-swing lever is more than 8 ft long.

38 Model of Tyre Bender 1891

Scale 1 : 4

This is an early example of a machine for bending a bar of iron into the form of a hoop, or for trueing up the hoop or tyre after the ends have been welded together.

The machine has three horizontal rolls, the middle one, which is driven by a four-armed handle, driving one of the side rolls by spur gearing. The bar to be bent passes under the central roll and over the two outer rolls, the undriven outer roll being adjusted on sliding bearings to give the desired curvature. To enable a welded tyre to be rolled the central roll is capable of being quickly withdrawn through its front bearing, so that the ring can be placed in position. A simple form of tyre drilling machine, with an adjustable rest, is combined with the bender.

39 Machines for Tinplate Working Nineteenth Century

This collection of machinery and tools formed the equipment of George Callam & Co, tinsmiths, of Edinburgh. It contains the following small hand-operated machine tools: wire drawing bench, Roys & Wilcox bending machine, three folding machines, two bending machines with straight rollers, bending machine with curved rollers, angle bending machine, burring machine or jenny, rotary shearing machine, bottom-closing machine, beading or swaging machine, fly press, pipe-bending machine, small rolling mill.

40 Model of Hydraulic Forging Press 1885

Scale 1 : 8

The pressure method of forging, introduced by J. Haswell in 1861, is considered to produce a more uniform flow in the metal than is to be obtained from the blows of a hammer.

The anvil is secured to side standards built in masonry, and the tup is formed as a crosshead, from which descend through guides two tie bars to a similar crosshead below the anvil. A small hydraulic ram below the lower crosshead tends always to lift it, so that the tup is normally up.

Three rams, acting downwards from the anvil to the lower crosshead, press the tup down when the pressure water is admitted into them; the forging pressure of one, two, or three rams being exerted as required.

41 Model of Chain-pressing Machine

Scale 1 : 8

Many attempts have been made to produce chains of the ordinary type which should be without weakness due to the welds, and such chains have been manufactured by cold punching from a cruciform bar, but their size was limited and the cost high. Weldless chains can, however, be successfully made by impressing the link form upon red-hot steel bars of cruciform section, and the model represents a machine for this purpose, patented by A. G. Strathern in 1897-1904.

The machine consists of a heavy framework having four horizontal crankshafts geared together. Each crank actuates a slide working in diagonal guides, and the slides carry at their inner ends pivoted quadrants to which the pressing dies are attached. The dies are formed as segments of a circle with a double bevelled edge upon which the link forms are cut, and they each enter one of the angles of the cruciform bar. The die faces are mounted eccentrically with the pivots, so that the inward pressure causes them to rotate and press and feed forward the bar at the same time. When the dies have completed a stroke they are withdrawn and returned to their original position, the bar remaining stationary until they are again fed forward. The actual machine is provided with a means of adjusting the dies, and a water service is arranged to cool them after each revolution. The machine is placed close to the front of a furnace 40 ft in length and the bars travel through at a speed of 20 ft per minute, being sufficiently heated during their passage.

On leaving the pressing machine the chain is held rigid by thin webs of metal surrounding the links and when cool it is passed through other machines which remove the webs, separate the links, and finish them to the correct size and shape. The links are made with thickened ends and the machine produces chains from $\frac{1}{4}$ in to $\frac{5}{8}$ in diameter, and from 60 ft to 90 ft in length.

42 Bending Machine

This type of machine, patented by W. Kennedy in 1903-9, is used for bending tubes or rods of various sections when cold, without distortion. It consists of a cast-iron body having a screwed mandrel projecting upwards from its centre with a stop at one point in its circumference. Rings or formers of the required radius, with their outer faces grooved to fit the tube or rod to be bent, are placed on the mandrel and an adjustable top plate is screwed down above them. An arm, pivoted at the top of the mandrel, carries a vertical pin having upon it a grooved roller which is at the same level as the former. The work is laid behind the stop and the roller is placed behind the end to be bent, the top plate being screwed down so as to prevent any flattening. The arm is then revolved and so wraps the work round the former, through whatever angle is required.

For the smaller sizes the arm is revolved by a lever fitted to it, but for the heavier sections gearing is employed. The pin carrying the bending roller has a pinion on its lower end, which gears with teeth cut round the body, and is rotated by a ratchet lever on its upper end.

This example will bend iron pipes up to 1 in diam, and brass or copper pipes, unloaded, up to 1¼ in diam. With suitable formers it will also deal with angles, channels, etc. The mandrel is 4¼ in diam, and six rings are shown for pipes of ⅞ in, 1 in, and 1¼ in diam, having radii of 3 in and 4 in respectively.

43 Wire-drawing Bench

This draw bench, which probably dates from the last decade of the eighteenth century, was used by four generations of the Hentsch family, makers of instruments for eye surgery. Wire was successively reduced in diameter by drawing it through dies supported by the pegs at the end of the bench. Traction was obtained by attaching the wire to the strap which was wound on to the drum by turning the winch.

44 Wire Straightening Machine 1908

This is a small appliance for straightening wire. It consists of a cast-iron base plate having mounted upon it five grooved pulleys or rollers, placed alternately on each side of the wire, which is drawn between them, the smaller sizes by hand and the larger sizes by a draw bench. The end rollers are fixed in position while the intermediate ones are mounted on blocks, clamped by bolts whose heads move in transverse slots, thus giving the necessary lateral adjustment. A guide is fitted to lead the wire from the coil to the first roller. The machine will straighten wire from 0·1 in up to 0·25 in diameter.

45 Revolving Head for straightening wire 1912

The old method of straightening considerable lengths of wire was by drawing it between inclined pins fixed in a slab, the pins being so set that they bent the wire slightly in opposite directions during its passage. Adjustable rollers superseded the fixed pins and improved action was obtained by using two sets of rollers in series, the second set acting in a plane at right angles to the first. A revolving head, carrying adjustable dies, between which the wire passed, was introduced about 1870, and this perfected the action by operating equally all round the wire; further improvement was effected, as in this example, by the use of hardened and polished steel rollers, instead of dies, thus reducing the friction on the wire and the power required to drive the head.

The head consists of an open hollow spindle running in ball bearings and provided with a pulley at one end. It contains five rollers, fitted in slots cut through cylindrical pieces that pass transversely through holes in the spindle; these pieces are adjusted radially by set screws bearing on their ends. The wire is drawn through the head by a suitable gripping device.

This example straightens wire from 0·036 in to 0·128 in diameter; it is driven at about 1,500 rpm, and requires about 1 hp.

46 Power Press 1938

This is a small bench power press, electrically driven, with automatic feed to take 1 in strip.

47 Hand Press 1938

This is a hand-operated fly press with 3½ in stroke and 1⅝ in screw diameter.

Welding Machines

48 Butt Welding Machine

This is one of the earliest resistance welding machines made by the Electric Welding Company under Elihu Thomson's patents of 1886. Parts up to 3 square inches in section could be welded and the maximum power expenditure was 40 Kw. The apparatus comprises a transformer, powerful screw clamps to hold the work; and a lever, ratchet, and screw mechanism for forcing the parts together. There is provision for water cooling (*see* **49**).

49 Electric Welding Machine

This is a small machine, made by the Electric Welding Co Ltd, for welding wire by the process introduced by Elihu Thomson in 1886, in which the heat is produced by the passage of a heavy electric current through the proposed joint while the parts are pressed together.

The pieces to be welded are prepared by having their ends made slightly convex and are then firmly held in clamps, one of which is urged towards the other by an adjustable spring having a controlling handle and locking arrangement. The clamps are insulated and form the terminals of the secondary coil of a step-down transformer, the low resistance of which causes the heating to be confined almost entirely to the junction, at first through the imperfect contact and afterwards through the higher resistance of the hot metal; the convexity of the ends, moreover, causes the welding to commence at the interior, so that any scale is expelled and a good joint is obtained throughout.

The controlling handle, which regulates the approach of the terminal clamps, has an adjustable sector connected with an arm operating a switch in the primary circuit of the transformer, and is so arranged that when the clamps have approached each other sufficently, through the up setting of the metal, to ensure a good joint, the circuit is automatically broken.

50 Electric Welding Machine

This wire welding machine made in 1947 is generally similar to No 49. The gaps between the vices can be varied by $\frac{1}{8}$ in, as used when welding small pieces, up to 3 in for annealing without interfering with the welding settings. This enables a joint to be annealed immediately after welding. The calibrated upsetting-pressure spring is placed on the side of the aluminium body which encloses the transformer.

Lathes

See also **129, 202, 209, & 239**

51 Primitive Lathe from Egypt

(*See plate 6*)

This is a modern example of the primitive type of bow lathe which has been used in the East since ancient times.

At the right-hand end of the wooden base board is fixed a transverse wood block which is connected with a similar but movable block at the other end by means of a stretcher. The iron centres are carried in these two blocks and the distance between them is adjusted to suit the length of the work by moving the loose block towards or away from the other and then fixing its position by wedging the stretcher in the square hole through which it passes. A long iron bar is laid across the blocks parallel with the centres and this serves as a tool rest.

The turner sits before the lathe on a slightly raised seat with his heels on the stretcher and his toes on the rest bar. He holds the handle of the tool in his left hand and guides the cutting end by the toes of one foot. The work is rotated by means of the forward and backward movement of a bow held in his right hand, the string of the bow passing around the work so that the direction of rotation is periodically reversed. Cutting is performed only when the work is turning towards him.

Some of the wooden gauges employed and a drill for use in the lathe are shown together with examples of the kind of work done in this type of lathe.

Photograph showing the method of using an eastern lathe (in Baghdad).

An Arab pipe as an example of primitive lathe work.

52 Model of a Chinese Wood-turning Lathe

Scale 1 : 10

The model was constructed in the Museum after a sketch made by Mr E. J. Jordan in Hankow in 1909. This lathe, which with the exception of the iron centres is made entirely of wood, consists of a long rectangular frame on trestles. One centre is embedded in one of the end members and the other is in a cross-piece which is wedged in grooves in the sides of the frame and can be moved to accommodate work of different lengths. The tool-rest is a bar which is supported at one end on the cross-piece and at the other on a movable bridge.

The work is rotated by an assistant who pulls alternately on the ends of a cord passing a few times round the work. As in the bow lathe and pole lathe the turner can only cut when the work is rotated in one direction.

53 Model of a Chinese Wood-turning Lathe

Scale 1 : 10

The model was made by Mr Jordan after a lathe seen by him in Hankow in 1909. The turner sits on a seat within the framework of the lathe and leans over a bar, which carries the tail centre, towards the headstock. He rotates the work alternately in each sense by means of a cord which passes a few times round the mandrel and is attached at each end to a treadle, one for each foot. A long bar acts as a tool-rest and there is also a rest for the turner's right elbow.

54 Pole Lathe

(*See plate 9*)

Pole lathes came into use not later than the thirteenth century and may have been the European development of the primitive Eastern lathe. In the Eastern lathe the turner is seated on the ground, but in the pole lathe the centres have been raised to suit the standing posture and the hand-operated bow has been replaced by a spring beam, or pole, and treadle. The lathe bed consists of two oak beams mounted on posts and the headstocks are massive blocks of oak passing between the beams and each carrying an iron centre. One headstock is fixed ; the other is movable and may be clamped in any desired position. A simple hand tool rest is provided. The driving cord is attached to the free end of the pole, passes around the mandrel or the work if a mandrel is not in use and then between the bed to the pedal below. The rotation of the work is thus alternately towards and away from the operator who cuts only when it is rotating towards him. This lathe was made about 1800.

55 Pole Lathe

This lathe was used for turning the legs of Windsor chairs by a 'bodger' working in the neighbourhood of High Wycombe. It forms part of a collection of chairmakers' tools, and was in use until c.1953.

56 Great Wheel Lathe

(*See plate 7*)

This lathe forms part of the equipment exhibited in the reconstruction of a wheelwright's shop. It came from Barley, Herts, where it was used until 1949 by four generations of wheelweights for turning the elm hubs of waggon wheels. The lathe was driven by an assistant who turned a crank handle attached to a flywheel 6 ft 6 inches in diameter mounted in a stand 8 ft away from the lathe. A 37½ in pulley is bolted to the flywheel and drives by means of a rope the 7 in pulley on the lathe mandrel.

57 Ornamental Turning Lathe

This treadle lathe was probably made in the late seventeenth century. The headstock and tailstock are secured to the wooden bearers forming the bed of the lathe by means of wooden wedges driven through slots in the uprights. The five-speed pulley on the mandrel may be driven rapidly for plain turning by means of the treadle and flywheel, which is of solid wood and provided with six grooves for the driving band. The slide-rest has a single slide the screw of which has the same pitch as one of the guide screws. The screw carries a circular scale with six divisions.

The nose end of the mandrel runs in a cylindrical collar and the pointed back end is supported in a hollowed adjustable centre. When rose-turning the collar is released by removing a locking screw so that it is free to swing about a pivot in the headstock. The mandrel carries a group of ten rosettes, any one of which may be made to press against a rubber, which may be fixed anywhere along a bar running parallel with the mandrel. The rosette is kept pressed against the rubber by means of a spring which is connected with the collar by a cord. As the spring is placed for convenience at the back of the lathe, the cord passes over a small pulley on the headstock so that the collar is pulled forwards. The tension is adjustable in five steps. A stationary tool applied to the work will thus cut a wavy line. For rose-turning the mandrel is rotated slowly by means of a winch-driven pulley attached to the front of the lathe bed. A rosette fitted at the nose end of the mandrel has waves on the face in addition to those on the edge. Five guide-screws of different pitch are cut on the rear portion of the mandrel. Below each of them is a wooden bearing which has the corresponding thread impressed upon it, so that it may be used as a screw key. If one of these keys is raised, by inserting a wedge below it, to support the mandrel, the latter advances as it rotates, so that a screw-cutting tool of the same pitch held against the work mounted in the chuck will cut a screw. This is the oldest method of cutting screws in the lathe.

The equipment of the lathe includes a hand rest, two poppet heads, slide-rest tools, turning tools and chasers. There are also an eccentric chuck and an oval chuck which are probably of later date.

58 Ornamental Turning Lathe c.1740

(*See plate 15*)

This bench lathe of an early type was probably made in France. It belonged to the second Earl of Macclesfield, who was President of the Royal Society from 1752 until his death in 1764.

The lathe has a double iron-bar bed with heavy brass clamps for fixing to the bench. It is driven from a pulley on an overhead shaft which is carried in a block sliding in a frame fixed to the bench. A hand-driven fly-wheel with a leaden rim is fixed to the shaft and drives a two-speed pulley on the mandrel, the belt tension being adjustable by moving the block up or down by means of a long square-threaded screw.

The headstock is pivoted between the bars of the bed in blocks at either end which are clamped to the bed and which extend upwards to carry a device for holding the headstock in a central position when it is not desired to use the lathe for turning rosettes.

The mandrel rotates in white metal bearings, and is able to slide longitudinally although normally held in its back position by a spring. For screw-cutting, three guide screws of different pitches are cut on the back portion of the mandrel and each screw has beneath it a short lever with a portion of threaded surface that engages the screw and traverses the mandrel when the lever is held up by a wedge. The mandrel is screwed, at both ends to take chucks. At the rear end rosettes are mounted, but if fitted with a faceplate and provided with a rubbing tool held in a rigid tool post fixed to the bench, the lathe may be used for copying medallions, etc. A number of rosettes are shown on the mandrel and when in use are kept pressed firmly against the rubbing tool by a serpentine spring fixed to the bench. The rubber support is adjustable in height and provided with three clamps.

The slide-rest is of the French form in use early in the eighteenth century. It is adjustable for height by a vertical screw and may be firmly clamped at the desired level by a single bolt which passes through the body of the rest and through slots in the movable portion. Screw traverse in one direction is provided and also a slide at right angles on which the tool is carried. A screw passing through the moving part of this slide abuts against the fixed part so that the depth of cut may be regulated.

The equipment of this lathe includes an oval chuck of English pattern, an eccentric chuck, and several other chucks.

59 Rose Engine Lathe c.1750

(*See plate 8*)

This elaborately decorated German lathe was made about 1750 for ornamental turning. The lathe was driven from a pulley on a overhead shaft carrying a treadle-driven flywheel supported in an adjustable bearing box. This is carried by a framework secured to a massive wooden cabinet, with which the lathe was combined. The framework is concealed by a mass of rococo decorations.

The mandrel headstock is hinged below and provided with a strong spring to keep any one of the several cams or rosettes in contact with a fixed rubber. The motion thus imparted to the mandrel caused a stationary cutting tool to produce on the work a wavy line or rosette instead of a true circle. By this means patterns suitable for decorating watch cases and snuff boxes could be produced.

Another set of cams is arranged to give end motions to the mandrel, so that a cylindrical surface could be ornamented, or lines cut of varying thickness on face work. The headstock could be clamped by screws for ordinary turning.

60 Ornamental Turning Lathe 1768

This French 'Rose-Engine', made by Hulot Fils, is a typical example of its period. The headstock carries a mandrel which is free to move longitudinally in its bearings, whilst the whole headstock can move laterally on fulcrums.

On the mandrel is mounted a series of rosettes having both edge and side serrations which bear against rubbing pieces carried in two side frames. Under the influence of the rubbing pieces the serrations cause the mandrel to move rhythmically either laterally or longitudinally as desired, being held in contact with the rubbers by plate springs. Thus wavy lines, varying in pitch or depth, are produced by the cutting tool on the surface of the work. The mandrel is driven from a treadle shaft and the arrangement of belt pulleys on the mandrel and back shaft gives the effect of backgearing.

Various forms of chuck can be mounted on the mandrel nose. An early and somewhat unusual type of elliptical chuck is shewn dismantled.

The tool rest consists of a main slide which can be set for either sliding or surfacing, with a subsidiary tool slide and tool holder set at right angles, both movements being made by hand-operated screws. The tool rest has a screw-adjusted stop for setting the tool.

In the same case is shewn a separate headstock by the same maker fitted with guide screws for cutting threads. To this headstock is screwed a double eccentric chuck.

A spherical or dome chuck of about 1815 by Holtzapffel is also included in the equipment of this lathe.

61 Treadle Lathe late eighteenth century

The use of treadle and flywheel to give continuous rotation in the same direction was introduced in the fifteenth century, but the pole lathe remained more common until the end of the eighteenth century. This lathe has a wooden bed and a headstock with taper bearing for the mandrel. The flywheel is made from a single piece of timber.

62 Watchmakers' Fusee Engine eighteenth century

This is a small screw-cutting lathe which was designed for cutting fusees· A fusee is a tapering drum of hyperbolic section with a screw-like groove cut on it, on which is wound a cord connecting the main spring of a clock or watch with the driven mechanism. It was formerly used for maintaining a constant driving torque as the spring unwinds.

The fusee blank is held in a chuck which is rotated by turning the handle. The shaft is threaded and carries a nut, which is attached to a perforated lever, which is pivoted at a corner of the frame. The cutting-tool holder is attached to another perforated lever pivoted at the opposite corner. A rod links the two levers so that the motion of the nut on the lead-screw is transferred to the tool, which thus cuts a thread on the blank. The pitch of the screw cut depends on the position of the link-rod, which may be altered by moving the pegs.

This type of fusee engine was described and illustrated by Antoine Thiout in *Traité de l'horlogerie*, 1741, who attributed it to Regnault of Chalons.

63 Watch Fusee Engine

(*See plate 21*)

This machine tool for cutting fusees (*see* **62**) is of a type used in the second half of the eighteenth century. It resembles the fusee engine illustrated in Ford, Whitmore, & Brunton's catalogue of c.1775.

The engine is intended to be mounted in a vice, and when the handle (not original) is turned, it drives through pinions the chuck holding the fusee blank. At the same time a threaded block travels along the screw cut on the shaft and turns a lever pivoted at the front of the frame. The movement of the lever makes the table carrying the cutting tool traverse at a rate which depends on the position of its point of attachment to the table, which is adjustable.

64 Clockmakers' Fusee Engine

This screw-cutting lathe, probably of early nineteenth century date, is of a type designed in the mid eighteenth century for cutting fusees.

When the mandrel which carries the fusee blank is turned by the handle (not original), a pinion on it rotates. The pinion is in mesh with a rack which is thereby caused to travel at right angles to the axis of the lathe. The rack-frame carries a bar, the inclination of which is adjustable. The cutting tool is carried by a slide-rest which is restrained by guides to move parallel with the mandrel. The slide-rest also carries a saddle at one end which passes over the inclined bar. Consequently when the rack travels across the bed of the lathe, it causes the tool-holder to move along the bed at a rate which depends on the inclination of the bar and which thus determines the pitch of the thread cut in the blank.

65 Watchmakers' Fusee Engine eighteenth century

(*See plate 20*)

This small screw-cutting lathe, which was intended to be clamped in a vice, was designed for cutting fusees.

The cutting tool is held in a holder which is constrained to slide parallel to the mandrel, on which a screw thread has been cut. On rotating the mandrel and the work held in the chuck, an elongated nut, which communicates with the tool holder through a lever, runs along the screw and causes the tool to traverse. The pitch of the screw cut depends on the leverage employed, which is adjustable by altering the position of the fulcrum.

66 Watchmakers' Fusee Engine c.1800

This small screw-cutting lathe, which was intended to be clamped in a vice, was designed for cutting fusees.

The cutting tool is held on a slide-rest which is constrained to slide parallel to the mandrel which is threaded with a coarse screw. On rotating the mandrel and the work held in the chuck, a nut, which is attached to the slide-rest through a lever, runs along the screw and causes the tool to traverse. The pitch of the screw cut depends on the leverage employed which is adjustable.

67 Watchmakers' Lathe eighteenth century

This is an iron lathe of primitive type with two plain centres and a simple hand rest. It was held in a vice and a bow was used to rotate the work.

68 Millwright's Lathe

This old millwright's lathe is capable of taking work up to 10 ft long and 25 inches in diameter. The bed consists of two wooden beams 14 ft long bolted to cast-iron standards.

69 Rose Engine and Accessories c.1800

(*Working*)

This lathe, made by Fieldhouse of London, is mounted on a slotted wooden bench, having a treadle and driving pulley below. The headstock consists of a casting carrying the mandrel bearings and pivoted on two pointed screws passing through sockets fitted into slots in the bench; an arm projects downward from the headstock and is connected, by an adjustable rod, with the lower end of a flat spring screwed on to the back of the bench. The bearings are of white metal, in halves, and are parallel so that the mandrel may have a certain amount of end play when required. The mandrel has a screwed nose, on which the various chucks are fitted, and behind it is a collar to take the thrust when turning. There are 32 rosettes, with different numbers of waves, one of which is fixed to the mandrel, while the others are keyed on a loose sleeve which can be rotated, relatively to the mandrel by means of a tangent screw and wheel, or by hand. The tangent screw is carried by a notched division plate, portions of which are divided into different fractions of the circle, and the pawl for this is carried by the driving pulley which is fixed to the mandrel. Thus the rosettes may be set in any position on the work and successive waves may be stepped round by fractions of the pitch of the waves, as is often required.

Some of the rosettes have waves on their side faces, so that when a suitable rubber is placed against them they give a longitudinal motion to the mandrel, and thus cause the tool to cut lines of varying depth; another adjustable spring, acting on the rear end of the mandrel, holds the rosette against the rubber. The two motions may be used together.

The lathe is fitted with a slide rest in which the transverse motion is given by a screw with a divided head, while the top slide which carries the tool is moved forward by hand, the depth of cut being regulated by an adjustable stop, when ornamenting a flat surface, but by a rubber fitted close beside the point of the tool when working on a curved surface. The rest has vertical and angular adjustments, and the tool slide may be replaced by another carrying a drilling spindle, which would be rotated by a belt from an overhead gear.

When preparing work the headstock is fixed by two screws and the mandrel is rotated rapidly by the treadle, but when ornamenting, the treadle is disconnected and the mandrel is turned at a slow speed by a hand gear fixed at the front of the bench.

The lathe is shown fitted with an elliptic chuck provided with two additional slides, moving at right angles to one another, which enables it to be used as a compound eccentric chuck also. The nose carrying the work forms part of a movable plate with 96 notches round its edge so that by the aid of a pawl the work can be set in certain positions as when describing a series of eccentric circles round the work (see **89**).

Another accessory is a straight line chuck. This consists of a vertical bedplate bolted to the front of the headstock, and a plate sliding in V-grooves in it which is moved up and down, by a partial rotation of the mandrel, by means of a chain wound on a pulley screwed on the mandrel nose. The sliding plate carries a notched division plate with a screwed nose, so that straight lines or waves may be cut across the work in any direction. The equipment includes two other special chucks, one for mounting, on a mandrel, prismatic work the faces of which are to be ornamented, and the other for mounting work with its axis at any angle with the axis of the lathe mandrel. A set of rubbers for the different rosettes and various cutting tools are exhibited, as well as specimens of the work executed.

70 Ornamental Turning Lathe, by Holtzapffel, 1815

The principal interest of this lathe attaches to the method adopted for rose turning. In the old type of 'Rose Engine' the headstock mandrel was caused to rock longitudinally or transversely, the tool remaining stationary. In this lathe the mandrel does not move, but equivalent motions can be imparted to the slide of the slide rest by means of rosettes mounted on a back shaft on the rear bed and driven through a train of gears from the mandrel.

The equipment includes a large number of special chucks and fittings which enable a wide variety of work to be undertaken.

Screws can be cut by traversing the work by means of guide screws mounted on the end of the mandrel in the manner employed in some of the early rose engines, or the more modern method of traversing the uppermost slide of the rest through a train of gears driven from the headstock may be used.

71 Screw-cutting Lathe c.1800

(*See plate 10*)

This lathe was constructed at the end of the eighteenth century, and is believed to be the first workshop machine in which Henry Maudslay combined a lead-screw and change wheels for producing screw threads.

The bed consists of two triangular bars, secured at a fixed distance apart and supported on feet by which it was secured to a bench; the height of the centres is 1·5 in and the length of bed about 3 ft. The headstocks are fixed to the back bar only; but the slide-rest, which is of gunmetal, slides on both bars and carries a toolholder which can be moved to or from the work in V-slides by means of a screw fitted with a graduated disc and a winch handle. Between the two guide bars is a metal lead-screw 1 in diam by $\frac{1}{4}$ in pitch, cut with a square thread which is, however, exceptionally narrow. This lead-screw was presumably geared to the lathe spindle by change wheels (now missing), while a split nut and a clamping device at the bottom of the saddle formed a connection between the saddle and screw which could be released when desired. The provision of the split nut and the very easy means by which the lead-screw can be removed, as reference to plate 10 will show, has however, led to the theory (propounded by Edwin A. Battison in *United States National Museum Bulletin 240*) that the gear ratio was in fact fixed and that a change in pitch of the screw to be cut was obtained by changing the lead-screw and the nut.

72 Screw-cutting Lathe c.1800

This small example of his original screw-cutting apparatus was made by Henry Maudslay.

The lathe is arranged for driving by hand power; the screw to be cut is carried between centres, while the lead-screw is low down in the bed, and a wide saddle which carries the upper rest, or tool holder, is connected to it by a form of split-nut, adjustable from below; the saddle also carries an adjustable stay to prevent springing of the rod being screwed, while the depth of the cut is controlled by a hand wheel with a graduated edge. The lead-screw has 30 teeth to the inch and on its axis is a wheel of 24 teeth which, through an intermediate wheel, gears with a wheel of 45 teeth on the lathe axis, so that the screw being cut has 16 threads to the inch. The lathe is provided with 28 change wheels with teeth varying in number from 15 to 50; the intermediate wheel has a wide face and is carried on a swinging adjustable arm so that it can connect wheels of various diameters at the fixed centres.

With the lathe is shown a collection of screwing tools, both with single cutting points and the various forms of multiple-point cutting tool or chaser, while samples of screws having from 16 to 100 threads to the inch are shown. There are also two pairs of wide calipers used for measuring the diameter of a screwed surface, and these are provided with long ends which increase the reading in the ratio of 4 : 1.

73 Lathe c.1810

(*See plate 12*)

This treadle lathe with triangular bar bed is of a type manufactured by Henry Maudslay for sale to amateur mechanics and small workshops. The bed is carried on two short standards fixed to the bench and, except when a gap is required for work of large diameter, slides into a triangular hole in the body of the headstock. For ordinary purposes the slide-rest fits directly upon the bed, but for screw-cutting it is mounted, as exhibited, upon an adaptor which protrudes at right angles. In this position the long lower slide of the rest is parallel to the line of centres and the traversing screw is connected through a keyed shaft to an appropriate train of wheels which is mounted upon a radial arm and driven from a pinion on the mandrel. The upper slide of the slide-rest is carried on a swivel and can be set at any desired angle. The design of the loose headstock is unusual in that the steel centre and the screw which moves it are not made in a single piece but separate; the centre slides in a long bearing and is pushed forward by contact with the end of the screw.

In order to keep the driving cords taut the overhead pulleys are mounted upon a pivoted frame which is balanced by counterweights.

The lathe is mounted on a bench with drawers and is equipped with a hand-rest and collar plate, a two-jaw independent chuck, and various other chucks and tool-holders. Fully equipped it was placed on the market at approximately £200.

74 Slide Lathe 1817

(*See plate 11*)

This lathe was made by Richard Roberts in 1817 and was in use at his works until 1854, and subsequently at the works of Messrs Beyer, Peacock & Co, until it was presented to the Museum in 1909. One of its features is the self-acting saddle which slides directly upon the lathe bed, and is thus able to traverse its whole length. The ordinary slide-rest of the period was a self-contained appliance, clamped to the bed where required, and only able, without being reset, to turn work of the length commanded by its short screw. Another feature is the compact form of back gear, giving increased range of speed, which has since become general, and was probably originated by Roberts.

The lathe bed consists of three vertical members strongly braced by cross webs, and with legs bolted to it at the ends; the upper edges of two of the members form guides for the headstocks, the rear one being an inverted V, and the other, which is directly beneath the lathe centres, being a narrow flat face. The saddle is carried, at the front, entirely by the third member, which has bevelled and faced top and bottom edges. The fast headstock has a mandrel with parallel bearings, and the thrust is taken by a flat-nosed tail screw. A spur wheel is keyed to the mandrel near the front bearing, and four-speed cone pulley, with a spur pinion at its rear end, is mounted loosely behind it; these are connected together for direct driving, or left separate when using the low gear. A counter-shaft is placed at the back of the headstock, and carries a spur wheel and pinion gearing with those on the pulley and mandrel; its bearings are supported in horizontal slides, which are actuated by two cam levers connected by a handle bar, so that it may be easily put into or out of gear. The saddle is traversed by a long screw carried in bearings at the front of the bed, and driven from the mandrel through a variable speed gear and a bevel wheel reversing and disengaging gear. It is fitted with a long solid nut embracing the screw, and geared to a winch handle, the rotation of which moves it along the bed; when, however, the handle is prevented from rotating by a pawl and toothed wheel attached to it, the rotation of the screw will give motion to the saddle. The feed gear consists of a flat plate wheel, with its axis normal to the mandrel, having seven circles of pin teeth projecting from its upper face which engage with the teeth of a sliding pinion mounted upon the tail of the mandrel. The plate is mounted on the top of an inclined shaft, and is held in contact by a spring, so that a change of speed is easily effected by pressing it down and sliding the pinion along until it gears with the correct circle of teeth; the pinion, has a rim, engaging with annular grooves on the plate, to keep it in position. The inclined shaft is geared down by spur wheels and a countershaft, and drives, by a bevel pinion, two bevel wheels mounted loosely on the lead-screw, either of which may be connected with it by a clutch actuated by levers and a rod running the whole length of the bed, and passing through the saddle; a stop placed upon this rod will cause the saddle to disengage the clutch when it reaches the end of its traverse. The saddle is provided with a transverse slide carrying a hollow vertical pillar, in which the stem of the tool-holder is clamped. The tailstock is mounted on a separate base which fits the lathe bed, in order to provide for lateral adjustment of the centre. It has an internally screwed barrel the screw of which is held by an external bridge supported on two pillars; a clamping screw is provided.

The lathe centres are 9·5 in high, and will take work 6 ft long between them.

75 Screw-cutting Lathe c.1820

This lathe was made by Joseph Clement, a noted mechanical draughtsman and toolmaker of his time. The chief features of the lathe are the geared mandrel, the sliding table with its various gears, and the traversing slide-rest which is capable of end to end movement. Provision is also made for attaching a revolving cutter to the slide-rest for milling, fluting, etc. The overhead gear which is supported on three columns and is mounted at the back of the lathe bed plate, is provided with the necessary grooved pulleys and separate clutches, the main object of which is to enable the turner to connect the movement of the flywheel with the slide rest, or with various pieces of auxiliary apparatus held therein, such as drills, cutters, milling and fluting appliances. The bed of the lathe is 12 ft long and is supported on three specially constructed pillar type supports. The lead-screw is supported at each end of the bed by brackets with enclosed bearings and the necessary thrust collars. The diameter of the screw is 1⅞ in with a pitch of four threads to the inch. The two treadles are independent of each other. Thus two people can work on the same lathe bed, doing different and independent jobs.

76 Lathe 1823-27

This lathe was formerly used by Charles Babbage, FRS, in his experimental work. It was so constructed that several machine shop operations could be done by its aid at a time when separate machine tools had scarcely been developed.

The lathe bed is of cast-iron and is fixed to wooden supports. The height of centres is 6½ in, and the mandrel has a single pulley driven by a belt from a step pulley on the flywheel. The pulley has a division plate of 200, 180, 112, and 12 holes, with a plain index. The compound slide-rest was made in 1823-4 by Joseph Clement, and was the second of its kind. It has three slides; the lowest, of shallow depth, can be clamped in any position transverse to the bed. To this is bolted a slide, with a lead-screw of nine V-threads to the inch, capable of rotary adjustment through about 45 °; the topmost slide is traversed by this screw and has alternative positions for the tool-holder. The holder is fitted with a machine vice whose position can be adjusted vertically by a screw, and it is also capable of partial rotation, being divided on the edge for that purpose.

A slotted bracket which can be fixed in alternative positions on the lowest slide of the rest, is provided for attaching work which is to be shaped, planed, or slotted.

When it is desired to use the lathe for screw cutting, a chuck with one of the toothed wheels keyed on it is put on the mandrel. In gear with it is a train, according to the pitch desired, held on the quadrant bolted to the lathe bed, and ending in a wheel keyed on the end of the lead-screw of the slide-rest.

77 Model of Segmental Lathe 1830

Scale 1:12

This represents an early type of machine for turning cylindrical portions of objects in which complete revolution was either unnecessary or impossible. Such tools have been used for machining crank arms and valve links.

At the top of two tall standards which are extensions of the fast headstock of a lathe is a speed cone and flywheel, driving by reducing gear, an overhanging crank arm of adjustable throw. A connecting rod from the crank works a rack sliding in vertical guides and gearing into a spur wheel secured to the headstock mandrel so that, as the crank rotates, the work in the lathe is rotated to and fro through an angle that is determined by the throw of the crank. The length of the connecting rod is also adjustable so that the portion of the work being operated upon can be quickly changed. The lathe bed has an internal traversing screw, and carries a slide-rest, the tool-holder of which is of the hinged type usually found in planing machines.

78 Self-acting Lathe 1843

(*See plate 14*)

This 5 in treadle lathe made by J. Whitworth & Co embodies the improvements introduced by Joseph Whitworth. His patent of 1835 included the split nut by which the lead-screw of a lathe could be engaged at will so that the carriage could be caused to traverse and the mechanism by which the cross-feed could be actuated by the lead-screw. He also introduced the hollow box design of lathe bed, which is much more rigid weight for weight than the triangular bar construction of Maudslay's lathes besides giving protection to the lead-screw; and the conical headstock bearing, which takes end thrust.

This lathe exemplifies Whitworth's improvements. If the split nut is disengaged, the cross-feed motion may be obtained through a pinion meshing with the lead-screw. If, however, the cross-feed is thrown out of gear by the lever at the back of the carriage, the handle at the front may be used to give rapid traverse to the carriage. In this case the lead-screw functions as a rack. The treadle and flywheel of this lathe are missing and a dividing head has been added.

79 Lathe c.1870

This 6-in workshop lathe made by Joseph Whitworth & Co will take work up to 39 in long. A four-speed cone, together with back-gearing, provides eight headstock speeds.

The controls for the saddle and tool slide are placed in the apron and include a lever for engaging a split nut with the lead-screw for screw-cutting. Hand traversing is effected by a hand wheel and pinion which engages with a rack below the lathe bed. The cross-slide screw feed has a micrometer adjustment.

Both sliding and surfacing motions can be made self-acting by means of a drive taken from a slotted shaft at the back of the lathe bed. The shaft drives a worm wheel and a spur gear engaged with it, each of which drives a concentric cone, one connected with the traversing and the other with the surfacing motion. These cone clutches may be alternatively engaged by turning a handle at the front. This method of coupling, which was introduced by Shepherd, Hill & Co at the International Exhibition of 1862, can be adjusted to give way in the event of too heavy a cut being attempted, thus providing a factor of safety. The use of a separate driving shaft for the tool motions enables the lead-screw to be used for screw-cutting only and preserves its accuracy.

80 Watchmakers' Lathe c.1850

The mandrel carries at one end a chuck or face-plate with three holding 'dogs' or clamps for holding the work, and at the other end a pinion with diagonal teeth gearing into a wheel fixed on an axis parallel to the mandrel, and provided with a handle by which the mandrel is rotated. The mandrel is hollow, and is fitted with a cylindrical spindle having a conical point to centre the work by. A slide-rest is provided.

81 Watchmakers' Turns, Previous to 1870

These are two specimens of the miniature lathe known as a 'turn' or a 'turnbench', upon which, for many years, the small turning required for watches and clocks was performed; since about 1870, however, they have been largely superseded by more elaborate watchmakers' lathes.

The turn is held in a vice, and the work is rotated intermittently by a bow, or continuously by a hand-wheel and band; the bowstring or band is wrapped round a ferrule fixed on the mandrel carrying the work. One hand is used to rotate the work while the other guides the tool.

One specimen is a dead-centre lathe consisting of an iron bar with two headstocks formed in one with it; these headstocks are bored for the reception of the centres, which are clamped in the required positions by set-screws. The middle part of the bar is slotted to accommodate a bolt that clamps the tool rest in any position along it. Transverse and vertical adjustments are also provided for the rest.

The other specimen has two head-stocks, one of which is loose and may be clamped in any position along the bar; these support a rotating mandrel, upon the projecting end of which the work is mounted. On the mandrel is a pulley for driving with the bow, and an adjustable tool-rest is fitted.

82 Watchmakers' Lathe and Bow, French 1867

This is a form of watchmakers' lathe in which a rotation of the spindle in one direction only is obtained by using two rachet pulleys rotated by a bow with two cords.

83 Model of Gap Lathe c.1860

Scale 1 : 9

This treadle driven lathe was part of the equipment of a blacksmith's shop. The gap in the bed, which is however in one piece, enables work of large diameter to be turned.

84 Lathe 1889

This power-driven lathe was made by Messrs Herbert and Hubbard, of Coventry. It has a four-speed cone and back-gearing. It is capable of taking work up to 10 inches in diameter and 2 ft in length.

85 Turret Lathe

This is an early example of the turret lathe designed by Wilhelm von Pittler in 1892.

The tools, up to 16 in number, are fixed in a horizontal rotatable turret mounted on the carriage which can be advanced along the bed of the machine by turning a hand-wheel. The axis of the turret is parallel with but below the workspindle which is in line with the centre of the uppermost tool hole. A disc with the same number of holes as the turret contains for holding the tools, is fixed at the other end of the turret spindle. In these holes rods are clamped which act as stops to limit the travel of the tools. When the turret is advanced the corresponding rod comes up against a stop which is bolted in a longitudinal slot in the lathe bed. The rods are adjusted so that each tool travels to the required limit.

When the turret is withdrawn at the end of a cut, it is automatically indexed so that the next tool is brought to the cutting position. The automatic mechanism can be disengaged and the turret set manually when required.

The lathe is capable of taking work up to 7 in diameter. It is also fitted with a collet operated by a sleeve connected with a hand lever on the headstock and is suitable for turning bar stock.

86 Automatic Lathe

This lathe, which was manufactured in about 1890 by Ludwig Loewe & Co, of Berlin, is evidently based on the automatic lathe invented by C. M. Spencer in 1873.

The motions are derived from a camshaft below the spindle. The cam drum at one end has fixed strips which open and close the collet and advance the stock up to a positioning stop. The stop is brought forward for this purpose or withdrawn when machining takes place by the so-called protean cam with adjustable strips which is situated at the other end of the shaft. There are also two cams which move the cross-slides back and forth. These carry the tools for forming and parting off.

The machine is thus capable of turning small parts automatically from bar stock.

87 Ornamental Turning Lathe

This treadle lathe was made by T. Cooke & Sons of York in about 1880. It is fitted with lead-screw, back-gearing, and countershaft. Among the extensive equipment is a double eccentric chuck made by W. Hargreaves in 1829.

88 Prismatic Lathe 1897

This special lathe, patented in 1891 by Messrs Dahlgren & Svensson of Sweden, is for turning such sections as squares and hexagons. This it accomplishes by revolving the work between centres in the manner usual in turning, while using as a cutting tool a revolving cutter with several cutting points arranged in a circle and uniformly rotated.

The speed of the cutters depends upon the number of facets to be produced, and upon the diameter of the cutting path, and they revolve in the same direction as the work. Although the facets produced are not true planes the deviation can be reduced to an amount that is scarcely perceptible with a straight-edge. The action of the lathe is made clear by a model.

As set up for cutting hexagons, the revolving tool consists of three cutters, carried on a spindle at the back. The work, which revolves at half the speed of the cutters, is carried between centres mounted on a saddle by which the distances between the work and cutter axes can be altered. Both headstock spindles are connected by gearing to a lower belt-driven shaft, swinging arms being introduced to carry change-wheels, and give a flexible connection. The headstock holding the work is moved longitudinally by a screw thus automatically feeding the work along. It also has an arrangement by which the correct setting of the work in relation to the path of the cutters can be effected.

89 Lathe and Appliances for Ornamental Turning late nineteenth century

This is a foot lathe made by Holtzapffel & Co for ornamental turning.

The fast headstock has a parallel mandrel with long bearings, but for most classes of work the mandrel is pushed back until a cone on it thrusts against the front bearing, where it is retained in position by a long collar fitting over the back end and fixed to it. The face of the cone pulley is perforated with circles of holes to act as a division plate for setting out or spacing work. To the small end of the step pulley is attached a disc with a thick rim pierced with 72 large holes, in which pins can be inserted to limit the rotation of the mandrel by coming into contact with an adjustable stop; this is for the purpose of producing segmental ornament, the mandrel being turned through the required angle by hand or by a disconnecting tangent screw and worm wheel, which may also be used for dividing. For work between centres a poppet head or loose headstock is provided; there is also a collar plate to give circumferential support to long objects when being bored from an overhanging end.

A slide-rest is fitted having two slides in directions at right angles to each other. The lower slide with V-edges is very long and the screw is provided with a handle and micrometer wheel at one end, whilst its upper surface is graduated in inches and tenths. The slide is mounted on a swivel mounting with a lock nut and may be raised or lowered and set at any desired angle to the bed. The upper slide also has a feed screw and small micrometer wheel and a stop for ensuring constant depth of cut. The tool is held in a slot in the top slide by two vertical screws which pass through blocks held in the slot by flanges.

The oval or elliptic chuck in its present form was patented in 1764 by James Williamson and Joseph Spackman, but chucks identical in principle, although slightly different in construction, were in use in 1700.

The invention of the oval chuck has been attributed to Abraham Sharp (1653-1742); the earliest turned ovals were, however, copied from a guide in a rose engine. The chuck shown consists of a back plate screwed on the mandrel nose, and having on its face a front plate carrying the work and sliding between V-guides. The front plate is controlled by means of studs passing through slots in the back plate, and having flat cross-pieces, which are in contact with the exterior of a ring projecting from a frame, secured to the face of the headstock at the level of the centres by pointed screws, and capable of horizontal adjustment to obtain any required eccentricity. The work thus receives an oscillating motion across the mandrel, which causes it to recede from the tool twice per revolution, in such a manner that a stationary tool cuts on the work in any position true ellipses, the limit being a straight line when the point of the tool is at the centre of the mandrel. These curves have a constant difference between their major and minor axes, equal to twice the eccentricity of the guide ring; the strip between any two ellipses is consequently not exactly uniform in width. A hand tool can be used on the rest, but owing to the importance of constancy of height such work is simplified by the use of a slide-rest.

For cutting the short screws chiefly required for fastening together the parts of ornamental work, the mandrel is traversed and the tool held stationary. For this purpose the collar on the back end of the mandrel is replaced by one of a series of short guide screws; below this and attached to the headstock is a plate having around its edge segments cut with threads corresponding with the guide screws, and this plate is mounted on an eccentric pin, by which it can be put in and out of gear.

When screws or helices of greater length than the guide screws or of other pitches are required, the longitudinal screw of the slide-rest is connected with the mandrel by change wheels.

The equipment with this lathe includes an oval chuck and spiral apparatus by Holtzapffel, a slide-rest by J. H. Evans, and a universal cutting frame.

90 Jacot Tool

This is a specialised watch and clockmaker's lathe for burnishing pivots. The pivot projects through a small hole in the plate on the end of the runner and the burnishing tool is applied to the pivot while the latter is rapidly rotated by means of the bow.

91 Watchmakers' Lathes and Accessories 1910

General turning for watches and clocks was originally performed on 'turns', or 'turn-benches' (see **81**), but since about 1870 the ordinary lathe in miniature has been developed. The two specimens shown are similar to those made by Messrs Lorch, Schmidt & Co, of Frankfurt.

The lathe beds are formed from a round bar, with a flat on one side; headstocks, tailstocks, and tool rests are fitted on this and secured by clamping screws; the headstock has a projection below, which may be held in a vice or in an adjustable foot screwed to the bench. One of the lathes has a fast headstock with a three-speed cone pulley, division circle, and index; while the mandrel is hollow, and chucks, arbors, etc, are held in its nose by a hollow draw-in spindle. The headstock of the other lathe has a mandrel to which a faceplate with three dogs is permanently attached; these dogs work in curved slots and may be clamped in any position so as to hold a plate eccentrically; a sliding conical point is fitted in the mandrel for centring the work, and sight holes are provided through the faceplate for observing it. The tailstocks have cylindrical barrels, in which different centres or runners may be clamped. A compound slide-rest is provided, as well as two T handrests and a roller-rest for filing. One of the tailstock runners consists of a hollow spindle with an arm at the inner end; this arm is provided with a hole in which the stems of centring and drilling plates are clamped; these plates have conical holes in which the end of the work is placed, while one has holes partly parallel, to serve as guides for the drills, which are secured in a holder sliding inside the spindle. A pivot-forming appliance also fits on this runner; it consists of a disc with a number of flats on its edge, in each of which is formed a longitudinal groove. The end of the pivot is laid in one of the grooves, the other end being driven, and filed down until it sinks into the correct groove, the flat face acting as a guide to the file. Behind each groove is a centre dot, by means of which a centre pin, passed through the hollow runner, sets the disc correctly. Another runner with a tapered hole serves to hold any of the sinking cutters, drill holders, or plates shown; there is also one with a sliding drill holder operated by a lever. A set of small drills from 0·1 mm to 1·2 mm is included. When turning work between centres, an arbor with a driver plate and an adjustable arm for the carrier pin is fitted to the headstock; for lighter work small carrier pulleys revolving on dead centres are fitted to either head to tail stock; a set of 10 small carriers of the ordinary shape, but of very small size, is provided. A large number of pointed arbors, with pulleys fixed on them, are used for mounting work between dead centres. For supporting work on the headstock an independent four-jaw chuck is used, and also an eight-screw bell-chuck, a set of 20 split chucks from 0·4 mm to 5 mm diam., a set of five split step chucks for barrels, etc, and a set of chucks to which to cement the work. There are arbors for carrying circular saws, emery wheels and wooden chucks.

A set of chucks for polishing screw heads is included. Brass split chucks hold the screws while their heads are being polished, and lantern chucks hold them by the heads when polishing the points.

Other accessories are a universal cutting frame, with guide pulleys, and an eccentric cutting frame (see **104**).

The height of the lathe centres is 1·6 in and the beds are 8 in and 12 in long respectively.

92 Lathe with Compound Harmonic Slide-rest

H. C. Robinson in 1908 patented this lathe for producing turned solids the outlines of which are the curves, known as Lissajou's, formed by the combination of two simple harmonic motions at right angles to one another. In it the cutting tool is given the combined motion and so cuts the curves directly on the revolving work.

The work is mounted on an ordinary ornamental lathe headstock, and a bracket bolted to the end of the bed carries a short transverse shaft, the front end of which has a crank with a pin adjustable radially from 0 to 2·5 in. The crank pin engages with a hole in a block that slides in a vertical slot formed in a gunmetal frame, to which is bolted a long horizontal steel bar which is thus moved backwards and forwards with a simple harmonic action as the crank revolves. The crank shaft is driven through bevel and spur gearing from an upper shaft, which is driven by hand. The ratio of the speeds of these two shafts can be varied by using wheels of different sizes.

A compound slide-rest is fitted to the bed and for this class of work the saddle is detached from the lead-screw nut so that it can slide independently. The tool-holder slides in transverse guides on the saddle, and has a vertical slot and block adjustably attached to it, with which engages a crank pin fitted to a short shaft mounted in bearings on the saddle. This shaft is driven by a universally-jointed square shaft which passes through the square hole of the upper shaft on the left-hand bracket, so that the tool-holder is caused to move transversely with a simple harmonic motion at the same time that the saddle itself is moved by being clamped to the long bar driven by the main crank. The transverse crank is adjustable in length, and it can be clamped in any angular position relative to its driving shaft, and thus to the main crank. The tool can be set to the required depth by a screw and stop. The two harmonic motions may thus be of any relative amplitude, speed and phase. Specimens of work are shown made with different speed ratios and angles.

Lathe Accessories, etc.

See also **87, 130, 131, & 135**

93 Roman Flint Tools and Turned Shale

At Kimmeridge in the Isle of Purbeck, shale was used in Roman times for making such objects as cups, bracelets, buttons, and spindle-whorls. The perforated disc is an example of a turned whorl used with a wooden spindle for spinning.

The turning tools were provided with flint tips.

The other disc is a waste centre which has resulted from a lathe turning process. Many of these have been found and were at one time thought to have been coins and consequently were known as Kimmeridge Pennies.

94 Ornamental Turning, Italian, eighteenth century

This example of very delicate turning in wood consists of a series of very thin cups which fit into one another.

95 Nine Millwrights' Hand-turning Tools

96 Slide Rest by Holtzapffel c.1830

This belongs to the earliest type of English slide-rest for ornamental turning. It differs from the French slide-rests of the same period in having a V main slide.

The tool is advanced to the work by means of either a knob or a detachable lever, the depth of cut being regulated by a screw stop with a micrometer head.

Shown with the rest is a top slide fitted with drilling spindle.

97 Spherical Slide Rest

The upper portion of this rest, which was made by Holtzapffel in 1840, can be rotated in a horizontal plane by means of a worm and worm-wheel for the turning of spheres.

See Holtzapffel's *Turning and Mechanical Manipulation*, Vol V, pp 625-7.

98 Compound Geometric Chuck 1815

This is a chuck used in ornamental turning for producing cycloidal curves in great variety. It was invented by J. H. Ibbetson about 1815, and was a development of the geometric pen, an account of which was published by J. Baptist Suadi in 1752. The simple cycloidal chuck was known before 1815.

The geometric chuck consists of two parts, each of which produces an epicycloidal motion as the mandrel rotates. The interposition of one motion upon the other with the aid of change wheels enables a great number of designs to be constructed.

As the mandrel rotates, the first and second parts acquire a relative motion depending on the precise train of wheels chosen and may be made to trace any number of loops, each of which represents one revolution of the mandrel.

The work is mounted on the faceplate which rotates on an axis attached to the slide, and is driven by a train of wheels through a pinion which meshes with an internal and unseen train terminating in a wheel which is fixed to the slide of the first member, and which, therefore, revolves with the mandrel although eccentric to it. Thus the second part also generates a cycloidal motion and produces a number of loops which are interposed on the primary loops of the first part, which in turn are interposed on the circular motion of the back plate. By means of the slides the amplitudes of the motions may be varied, and a dividing wheel is fitted in each part to enable the curves to be placed in any particular position relative to one another or to the work.

99 Compound Geometric Chuck 1835

This example illustrates the improvements made between the date of the invention of the geometric chuck in 1815 and the period 1835. The chuck in its earlier state of development is represented by **98**.

Engraved on the faceplate is the following : *'Ibbetson's Geometric Chuck (1st, 2nd., 3rd., and 4th. parts) invented by In^{o}. Holt Ibbetson, Esq., of His Majesty's Vict^{g}. Office. The first of these Chucks was made by him in 1815 and this Chuck, made by his own hands, even to every screw, contains all his improvements on it up to Dec^{r}. 1835'.*

The rear detent gear wheel has three rows of teeth from which alternative trains of gears can be driven. These are mounted on the rear face of the plate, and drive, by way of a small spindle and gears, the gear trains on a quadrant plate which is carried on the forward face of the faceplate. The quadrant is capable of adjustment by hand or by a worm and worm-sector graduated in degrees. On the spindle on the quadrant plate are various toothed rings interspaced with which are three further quadrant plates carrying selective trains of change gears, and a further worm and sector adjustment. The complicated motions thus generated as the chuck rotates are conveyed to a secondary faceplate, which, in turn, carries a spindle furnished with an eccentric chuck of standard pattern. The work spindle of this eccentric chuck is furnished with a spacing detent and alternative worm and wheel movement with calibrations in degrees on the rim, by means of which the work is set.

100 Cutter Bar or Tool Holder

This is a form of tool holder suitable for an ornamental lathe.

A square bar, clamped in the slide rest, carries at its end an adjustable inclined head-piece secured by a screw. To the end of this head the pieces of steel forming the cutters are clamped by a strap and set screw. Two heads are provided, one for holding gouge-shaped cutters, and the other for cutters made from square bar.

101 Universal Cutting Frame

This is an appliance for the ornamental lathe by means of which such work as fluting, drilling, etc, may be performed.

A square bar, held in the slide-rest of the lathe, has its end formed as a circular flange with a graduated edge. Upon this flange a frame is mounted capable of being clamped in any position by a bolt passing through the axis of the bar; this frame carries a spindle, with its axis at right angles to that of the bar. The spindle is driven at a high-speed through bevel gearing, pulleys, and a belt, from an overhead gear. Three interchangeable spindles are provided, adapted for carrying fly-cutters, drills, and milling cutters respectively.

102 Geared Universal Cutting Frame

This form of cutting-frame enables a rotating tool to be set to cut at any angle with the axis of the lathe, including the horizontal and vertical positions. It is used for cutting and ornamenting cylinders or other surfaces in various ways and also for cutting the long spirals or helices frequently used in ornamental turning.

The appliance is held in the slide-rest by a square bar through which passes a longitudinal spindle. To the front end of the spindle is fixed a bent arm, that bears against a graduated collar formed on the end of the bar. A washer and screw at the rear end of the spindle serve to clamp the arm in any angular position and a pointer on the arm passes over the graduations and indicates the angle. At the end of the arm at right angles to the spindle is a boss, and this is fitted with a hardened steel bush with an internal cone. A steel spindle fits in this and projects towards the main axis, its end being fitted with a chuck for holding the cutters, which are secured in a mortise by set screws. The back end of this spindle has a spur pinion fixed to it, which gears with a spur wheel attached to the grooved driving pulleys and mounted on a fixed conical spindle. By mounting the cutters on the end of the spindle in this way, and gearing them up from the driving pulleys they are enabled to run at a high speed and to get close up to the work. This apparatus was made by J. H. Evans (d. 1919).

103 Drilling Spindle

This is a tool for ornamental turning by means of which various forms or flutings are cut on the work by a revolving cutter resembling a drill.

The tool consists of a square steel bar, made to fit the tool-holder of the slide-rest, and through this passes a spindle running in hardened steel-coned collars at each end of the bar. The front end of the spindle is coned to fit one collar, while the rear end is fitted with a loose cone, fixed to a steel driving pulley, which is held on the spindle by a screw, so that it may be adjusted to take up any wear. It is essential that the spindle shall always run without shake. The end of the spindle is bored to receive the drill shanks, which are secured by a set screw. Various forms of drills or moulding tools are used for such work as plain drilling, making beads and pyramids of various shapes, and cutting flutings. This apparatus was made by J. H. Evans.

104 Eccentric Cutting Frame

This appliance is used in ornamental turning for cutting circles of different diameters and at varying distances from the centre of a piece of work which remains stationary while the cutter revolves. When used with different tool shapes, and in conjunction with an eccentric chuck, a great variety of patterns can be produced. It may be used also for shaping up the flat faces of prisms and afterwards ornamenting them.

The tool consists of a square bar that fits the tool-holder of the slide-rest, and is bored longitudinally and fitted at the ends with hardened steel coned collars. Through this is passed a steel spindle, to the front end of which is attached a right-angled slide. A steel pulley with a cone attached is fitted to the rear end and is secured by a screw that serves to adjust the coned bearings. The right-angled slide carries a small tool-holder which is moved along it by a quadruple threaded screw with a divided head, by means of which the tool radius is set. This apparatus was made by J. H. Evans.

105 Specimens of Ornamental Turning

These ten specimens executed by J. H. Evans are examples of the work which may be done with universal and eccentric cutting frames (see **102** and **104**).

106 Specimens of work executed with the Eccentric Cutting Frame

These four pieces show the type of work executed with the eccentric cutting frame (see **104**).

107 Elliptical Cutting Frame 1800

This is an elliptical cutting frame working on the principle of the elliptical trammel. It is adapted to fit into a slide-rest of an early pattern and was probably made about 1800.

Attached to the front end of the frame in an adjustable position is a steel framework containing two slideways at right angles to one another. The drive is taken from a pulley at the rear of the spindle to a pin which moves in the first slideway through slotted links which allow free lateral movements. The pin is fixed to one part of an adjustable slide, the other part of which passes through a gunmetal block sliding in the second or vertical slideway and is fixed to a plate carrying the cutter frame. The eccentricity of the tool in the cutter frame is adjustable by a thumbscrew and, by altering this eccentricity and the eccentricity of the sliding pin, ellipses of varying sizes and proportions may be obtained. A simple example of its work is shewn.

108 Epicycloidal Cutting Frame

This instrument, introduced by H. W. Pomeroy about 1870, is a development of the elliptical cutting frame.

The cutting frame is held in the slide-rest by a hollow square stem. Rotating on the rounded front end of the stem is a two-speed pulley

directly fixed to the plate it drives. The latter carries a radial arm pivoted at one end near the edge of the plate and clamped at the other end by a thumb screw which slides in a curved slot. The frame carrying the cutting tool rotates in a bearing formed in the radial arm and is driven through a train of wheels terminating in a wheel central with the driving plate and fixed to a spindle which passes through the hollow stem. At the rear the spindle is held by a worm engaging in a wheel to which it is attached. Eccentricities are set on the cutter frame and radial arm by screws, and the axis of the arm being also the axis of one wheel of the driving train, radial movement of the arm does not throw the wheels out of gear.
For cutting ellipses the gear wheels are arranged to give a relative speed of rotation in the two parts of the cutter in the ratio of 2 : 1 in opposite directions. By varying the eccentricities all manner of ellipses can be drawn from a straight line to a circle, and by means of the worm and wheel at the back they can be placed in any angular position. For the production of cycloidal curves the ratio of 2 : 1 is altered by the introduction of other wheels into the train.

109 Examples of Ornamental Turning

These specimens indicate the kind of work of which ornamental turning lathes with the aid of special cutting frames and chucks are capable.
They represent some of the finest work accomplished and most of them are illustrated in Holtzapffel's *Turning and Mechanical Manipulation*, vol 5, 1884 (see **113**).

110 Ornamental Turnings

These seven specimens have all been generated from a single rosette in order to illustrate the variety of patterns which can be formed by this means.

111 Turned Ornamental Wooden Bowl

112 Turned Wooden Bowl, seventeenth century

This bowl with an elaborate lid is a three-storied wassail bowl. Diameter: 10 in, Overall height: 18 in.

113 'Turning and Mechanical Manipulation'

by Charles and John Jacob Holtzapffel, London, 5 volumes. 1843-1884
This is the greatest work on turning in the English language. Volume 5 with 600 illustrations is devoted to ornamental turning.

114 Threading Dial

This is a lathe attachment for use when screw-cutting to indicate when it is safe to engage the half-nut with the lead-screw. It is attached to the carriage, and the worm-wheel is in mesh with the lead-screw, so that, when the carriage is stationary, the dial rotates. The rotation of the dial through one quarter of a turn as marked by adjacent numbers on the dial coming opposite a fixed line indicates a lead-screw rotation equivalent to a 1 in movement of the carriage.

After cutting the first thread it is safe to engage for a subsequent cut at any number of the dial, if the screw has a whole number of threads per inch. For half pitches the same or opposite number as was used in making the first cut must register. For quarter pitches the half-nut may be re-engaged only when the same number comes opposite the zero line.

Threads in simple relation to the lead-screw may thus be cut without recourse to marking the lathe. The threading dial was invented in 1894 by Franz Braun.

115 Expanding Mandrel 1884

This mandrel consists of a tapered spindle having sliding upon it three correspondingly tapered wedges, which can be pulled along by a nut screwed on the larger end of the spindle and embracing a projection formed on each wedge.

The work to be turned is carried on the cylindrical external surface of these wedges, which are prevented from slipping on the spindle by three fixed keys. An annular spiral spring keeps the wedges in position when the mandrel is slacked back. The example shown is for work about 2 in diam, and has a range of $\frac{3}{64}$ in diam above or below this size, but by using the split bush the effective diameter is increased to $2\frac{1}{2}$ in.

116 Noble's Expanding Mandrel 1887

This lathe mandrel is adjustable so that it can be set to fit various diameters of bore, by means of three wedges, whose outer edges form parts of a cylinder, sliding in dovetail grooves cut on the enlarged central portion of the mandrel.

The bottoms of the grooves are inclined at the same angle as the wedges, so that a nut, which forms part of the lathe carrier, forces the wedges along until they fit the bore of the article to be turned. The mandrel is released by screwing up a nut on a left hand thread at the other end. The diameter of this specimen ranges for $1\frac{5}{8}$ in to $1\frac{7}{8}$ in.

117 Self-centring Four-jawed Chuck 1887

This lathe chuck, patented by Messrs Clark and Wellington in 1882, has four adjustable jaws, moved in and out by four radial screws. The screws are geared together by means of a ring with bevel teeth, housed within the hollow rim. The ring gears into four bevel pinions, one upon each screw spindle, so that all four screws work simultaneously when one is turned.

118 Capstan Slide Rest

This is an example of a capstan rest for lathes, patented by A. Muir in 1892. The capstan block is square and has a slot along each side in which four different tools may be clamped by set screws in the usual manner. This block turns on a pivot and is secured by a central clamping screw, while a spring stop in the base, engaging with grooves formed in the under side of the capstan, holds it in the correct position for each tool.

119 Magnetic Chuck 1912

This form of chuck, which is essentially a revolving electro-magnet, was used for holding washers, rings, or other articles difficult to chuck, and was specially useful for grinding operations.

The electro-magnetic chuck has the disadvantage that the accidental interruption of current can be dangerous. So, with the invention of the permanent magnet chuck in 1933, it is less commonly used.

120 Flat Magnetic Chuck 1919

This electro-magnetic chuck is similar in principle to the rotary chuck (**119**) and was intended for use on planing and grinding machines.

121 Drill Chuck

This drill chuck, the main features of which are its accessibility and the ease and rapidity with which drills may be removed and replaced, was patented by F. W. Kupke in 1910.

The drill shank is gripped by three jaws, whose back faces are inclined and bear against the cone-shaped inner surface of a steel ring, which fits freely in the recessed portion of the body. The jaws are pressed upwards into the cone, and so closed, by a cup or boss made integral with the spindle of the chuck, which is screwed into the body with a coarse square-threaded screw. The jaws are held vertically in position by three guiding slots cut through the spindle.

The upward thrust is transmitted from the jaws to the cone, and from thence through a ball race to a washer resting on a shoulder in the recess of the body. There is thus no thrust on the spindle, and no binding of the threads, and the drill may be released without stopping the machinery, by a quick blow on the boss in the direction in which the chuck is turning. By the action of the cone any increase in the upward pressure of the drill causes the jaws to grip more tightly. The chuck is assembled without screws, two spring rings being all that is required to keep the parts together.

122 Spiral Chuck 1921

123 Cemented Tungsten Carbide Tools

Tungsten carbide is an exceeding hard synthetic substance suitable not only for the rapid machining of metals but for cutting hard substances like glass. Its hardness, which approaches that of diamond, is retained to a large extent at red heat.

Tungsten carbide is made by sintering together tungsten, cobalt, and carbon. The carbides of other elements such as tantalum and titanium are also used for hard cutting-tools.

The carbide is used in the form of small inserts brazed to the steel body of the tool. The final shape is obtained by grinding.

Screwing Machines

See also **239**

124 Model of Screw-cutting Machine

This model has been made in accordance with Leonardo da Vinci's design on MS B, folio 70 V, which was written in 1488 and 1489.

Supported by bearings mounted on a table are two lead-screws which are geared to a crank which also turns the blank on which the thread is to be cut. The blank passes through a hole in the cutter housing on each side of which are nuts which thread the lead-screws. The cutter, which is wedged in its housing, traverses at a rate determined by the gear ratio. Change-wheels are provided so that screws of different pitch may be cut, and to accommodate wheels of different size the bearing blocks may be moved laterally.

The screw, which results, is of opposite hand to the lead-screws, but Leonardo incorrectly depicted all three screws with left-hand threads. Evidently Leonardo did not draw an existing machine and this suggests that the machine was an original conception quickly noted down with an error in detail.

125 Machine for Originating Screws

This appliance for originating screw threads was made about 1800 by Henry Maudslay. A cylinder of hardwood or soft metal is pushed into a metal tube and turned so that it engages with a crescent shaped knife which projects into the tube and is set at the appropriate angle with the axis. The knife in cutting into the cylinder causes it to traverse and a screw is thus generated which is deepened and cut to the required form by a following chaser. Copies in steel are then made of the screws thus produced.

The knife is carried by a holder secured to a large disc provided with a tangent screw adjustment finely graduated so that the knife can be set at the exact inclination. The depth of penetration of the knife and of the chaser are also set by screws.

126 Screwing Machine 1849

This machine was made by Joseph Whitworth & Co in 1849. The rod or pipe to receive a thread is held in a chuck at the end of a hollow spindle, which passes through the driving shaft and is keyed to a groove in the latter. The spindle can thus slide while rotating, so as to feed the blank into the die which is mounted in the tailstock of the machine. A ring fits loosely over a groove in the spindle behind the chuck and is attached to a rack which engages with a pinion, which can be turned by a hand wheel in order to bring the blank up to the die. The die, which has four cutters, is adjustable by a hand wheel.

127 Screw Rolling Machine

This machine, patented in 1851 and received in 1860, is intended for making single or multiple screw threads of different diameters from the same set of dies, and produces the thread, whether square or angular, by rolling compression.

Two steel plates or dies, having on their faces longitudinal grooves of the size and shape of the required screw thread, are placed on above the other at a distance apart suitable for the diameter of the screw. The upper die is attached to a block which can be raised or lowered by a screw, and the lower one is attached to another block which slides in horizontal guides and receives a reciprocating motion from a crank and connecting rod driven through spur gearing. The dies are adjustable in their blocks and are set so that their grooves are inclined at opposite angles to the direction of motion of the lower die, equal to the angle of the required thread. The rod or blank is placed between the dies, the upper one forced down upon it, and motion given to the lower one whereby the blank is rolled between the faces. Specimens of the screws produced are shown.

128 Model of Screwing Machine

This model represents a screw-cutting machine, patented in 1856, for cutting screws by hand or power.

The dies are held in a clamp which slides freely on two fillets, one on each side of a trough. The clamp is provided with a screw and a graduated scale for closing and setting up the dies, and a lever and latch for quickly opening them. The rod or bolt-blank to be screwed is held in a pair of jaws like a lathe chuck, and is caused to rotate. The machine can also be used for tapping nuts, a cross bar with a square recess or socket being then used to hold the nut stationary, and the tap being held by the jaws and rotated.

129 Automatic Screw Machine

This lathe, patented by C. W. Parker in 1879, for automatically producing screws, was made by Greenwood and Batley, Ltd. The screw blanks are turned from a metal rod, which is fed in through the fast headstock against stationary tools; these tools are then withdrawn and the screwing die advanced, and retired after cutting the thread; a parting tool then cuts off the screw. The heads are finished and nicked in a separate machine, but, originally, the machine was designed to perform these operations also.

At one end of the bed is a fast headstock with a speed cone and hollow mandrel; at the other end is a headstock carrying the threading spindle and its mechanism. A shaft runs through the bed and upon it the cams giving the requisite motion are mounted. The front end of the speed cone is fitted with a spring chuck that guides the rod which is being fed. A diaphragm is fitted near the rear end, to which the tail of the mandrel is fixed, and inside the hollow cone is a roller feeding device, which is arranged to accommodate rods of different diameters. The rollers are driven by skew-toothed wheels and spur gearing, from the end of the main spindle, through a toothed clutch, in the same direction as, but at a slightly less speed than, the spindle. When the rod has advanced to the correct distance, the clutch is thrown out of gear by a lever and cam; the spindle and sleeve then rotate at the same speed and the feed stops. The turning tools are mounted on a cross slide at the front and the parting tool is mounted on a slide at the back, and is connected with the front slide by an adjustable rod so that one bellcrank lever, actuated by a cam and weight, moves both slides.

The screwing gear consists of a hollow sliding spindle having the die fitted to its nose; this is driven from the main spindle in the same direction as, but at a higher speed than, the screw blank. The spindle is advanced towards the blank and is left free when the die has commenced cutting; when the thread is completed, the spindle is released, its rotation is stopped, and the die is permitted to unscrew itself. The cam shaft is driven from the main spindle through a countershaft, spur and bevel gearing, and its rotation is stopped and restarted by automatically engaging and disengaging the work and wheel.

Lubrication is supplied to the turning and screwing tools by a rotary pump, to the latter through the hollow spindle and a telescopic pipe. The machine will make screws from 0·125 in to 0·312 in diameter, with heads of any form; it will turn out from 80 to 150 screws per hour of 0·125 in diameter according to length. The main spindle runs at from 300 to 500 rpm.

130 Self-opening Dieheads

This form of diehead, which opens automatically at the end of the cut, was patented by P. V. Vernon and the manufacturers in 1902.

131 Collapsing Taps

This form of tap was patented by A. H. Lloyd and the makers in 1916. It collapses automatically and is provided with means for taking a roughing and finishing cut over the same thread.

132 'Coventry' Tapper 1923

This is a sectioned example of a reversible tapper, generally used in drilling machines, in conjunction with, or subsequent to, the drilling of the tapping holes.

133 Screw-thread Milling Machine 1897-8

This is the original machine constructed by Messrs Holroyd under H. Liebert's patents of 1897. The process of milling screw threads is more rapid for quantity production than the older method of turning them in a lathe since the screw can be finished in one pass.

The machine has a headstock with back gearing, carrying a selective cone pulley for belt drive. The cutter spindle is gear driven and is set below the pulley spindle in order to leave a clear space for the work beneath the cutter spindle. The headstock is set so that the axis of the spindle is at right angles to the tangent of the screw helix, and the cutter or cutters are so formed that the amount of material removed due to the arc swept out by them produces a thread which is correct in section.

The bar on which the thread is to be cut is mounted in a second headstock

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which rotates it and at the same time moves it past the cutters at the required speed, so that the combination of rotation and longitudinal movement gives the desired pitch of thread. This headstock is belt driven independently of the cutter headstock.

134 Screw-thread Grinder 1916

This machine was designed by J. H. Jones for grinding the threads on fuse-hole screw gauges, and was the first machine to grind successfully threads in hardened steel to the Ministry of Munition's limits of +0·0003 to —0·0006 inch in diameter.

The system comprises the use of a master screw mounted on the tail of the headstock spindle and working in a stationary nut. The spindle with the gauge is propelled past the grinding wheel as it rotates. This is an interesting reversion to the old system of cutting screws used in the early ornamental turning lathes.

The gauge blank is mounted between centres, the tailstock centre being spring loaded and giving to the travel of the gauge. In the headstock is a reversing mechanism operated by adjustable calliper-leg type of stops which swivel to and fro in sympathy with the movement of the spindle and engage with reversing pawls at the end of a pre-determined travel. The grinding wheel cuts the thread on both the outward and return travel, the feed of the wheel being applied by hand.

The wheel-trueing device consists of a carborundum dresser mounted on an arm at the back of the machine. This arm swivels through an angle of 27·5° on each side of the centre line, giving the angle of 55° for the standard Whitworth thread. The dresser is worked on both sides of the wheel by hand, forming a sharp pointed or a truncated V at the discretion of the operator. The desired radius on the top of the V is formed by using the newly dressed wheel for roughing out. The radius on the crests of the ground threads is formed by a separate wheel dressed with grooves at an angle of 90° and formed to shape on an old or rejected gauge.

135 Screw-cutting Attachment

This mechanism, shown incorporated in an attachment for a standard lathe, was produced to supersede the dial indicator and standard nut mechanism on screw-cutting centre lathes. The engagement and disengagement of the nut with the lead-screw is controlled mechanically with the result that threading can be carried out, using tungsten carbide tools, at extremely high spindle speeds.

Patented in 1955 by John Farrow and developed by the donors, the device is used with the existing lead-screw and controls the engagement of a half nut by means of a disc rotated by a pinion in constant mesh with the lead-screw. The disc is slotted and engagement can only occur when a pin enters a slot. By means of a screening device the number of slots can be varied to produce pick-up positions to suit whole or fractional numbers of threads per inch. A precision release is operated by a trigger coming into contact with a stop.

Drilling and Boring Machines

See also **103, 121, 132, 163, 213, 218, 223,** & **239**

136 Model of Boring Machine

This model has been made in accordance with Leonardo da Vinci's design in the Codice Atlantico, folio 393 R.b, which was written between 1483 and 1518.

It was intended for boring out logs for water-pipes and pump-barrels and is particularly interesting for its use of two connected self-centring chucks in which the log may be rapidly fixed in position, correctly aligned and centred. The chuck pair is made up of two fitting coaxial cylinders, the inner of which carries the chuck jaws, and is mounted on a bench. The outer cylinder, to which the handles are attached, has toothed rims which engage with threaded cog-wheels. When these wheels are rotated, the screws, which pass through them and to which the jaws are attached, screw in or out. By moving one of the handles, therefore, the jaws are made simultaneously to open or close.

The boring bit is attached to the front of a pulley which was presumably intended to be driven by a belt. The tool is supported near the chuck by a fixed bearing and is fed into the log by means of a lead-screw in the bench, which is turned by a winch.

137 Model of Gun Boring Machine, eighteenth century

Scale about 1 : 12

This model gun boring machine is a copy of a contemporary model in the Royal Artillery Institution, Woolwich, and represents the early method of boring guns, as depicted in Pieter Verbruggent's drawings of gun manufacture at the Royal Arsenal.

The gun is rotated on a horizontal axis by horse power acting through a large wheel and pinion, the muzzle end being supported in a ring guide. A 'D' bit probably used for finishing is shown in place and is fed into the bore by means of a rack and pinion operated by a hand wheel, the direction of the bit being kept as accurate as possible by the use of steel guides mounted on a heavy timber carriage. A simple form of slide-rest providing longitudinal movement for the tool is used for outside machining of the guns when necessary. The machine is bolted to a brick foundation which is buried beneath the surface of the earth.

It should be noted that the same scale has not been strictly adhered to throughout the model. Certain details, such, for example, as the holding down bolts to the foundation, are out of proportion.

In Smiles's *Industrial Biography*, pp 340-342, it is shown that the original model was made in 1782; and argued that Henry Maudslay, who was employed at the Woolwich Arsenal until 1789, must have been familiar with the gun-boring machine and its slide-rest.

138 Model of Cylinder Boring Machine c. 1770

Scale 1 : 12

This model which is based chiefly on the boring plant erected by John Smeaton at the Carron Ironworks in 1769, illustrates the best practice attained before the great advance in accuracy made by John Wilkinson in the Bersham boring mill (see **139**).

Until the advent of the Newcomen atmospheric engine in 1712 all boring appears to have been accomplished with simple augurs in the case of wood and with D bitts for brass and iron. Such bores rarely exceeded a few inches in diameter.

In Smeaton's mill the boring of large cylinders for the Newcomen engines was accomplished with the aid of a boring head which carried the cutting tools round its periphery. The head and its driving bar were unsupported except loosely at the driving end. Thus the weight of the head caused it to cut mainly along the bottom of the cylinder and, since it was guided solely by the casting itself, the resulting bore was neither circular nor straight. To rectify this to some extent the cylinder was bored in four settings, being turned through 90° at each setting.

Power is derived from an undershot waterwheel which drives two spindles through spur gearing, Thus three speeds are available for boring, by making use of the waterwheel direct, or by either of the spindles. The cylinder is mounted on a trolley working on guide rails, and is drawn over the cutting head by a chain tackle and windlass. There is little or no rigidity for the cylinder and truck.

See: *Smeaton's reports* 1812, Vol I, Vol II. Farey's *Treatise on the Steam Engine,* 1827.

139 Model of the Bersham Boring Mill 1775-1795

Scale 1 : 12 (*See plate 22*)

This model represents the boring mill established by John Wilkinson at Bersham near Wrexham, the first mill in which a boring bar supported at both ends was used. It was thus the forerunner of the modern type of machine. Its invention had a wide influence upon the progress of contemporary engineering practice for it enabled cylinders to be bored with much greater accuracy than had hitherto been possible. The success of the steam engine as developed by James Watt owed much to Wilkinson's machine and all Watt's early cylinders were bored upon it.

The mill is driven by an overshot waterwheel situated between two walls. Upon one side are the larger boring bar and a heavy facing lathe possibly used for turning cylinder covers, pistons or cutter-heads, and also the rails and truck which, it is presumed, were part of an old mill of the Smeaton type (see **138**) which was in general use previous to Wilkinson's invention. The lathe has a hollow mandrel in which the end of the bar carrying the cutter-head of the old mill was held. The cylinder was mounted upon the truck and was fed 'over' the rotating cutter-head. The success of Wilkinson's machine was due to the rigidity obtained by supporting the boring bar at both ends and by securing the cylinder.

Upon the other side of the wall is the smaller boring bar and a wooden-bed lathe with a long bed. The gearing used here has two rows of staggered teeth which would increase the smoothness of the drive and from this it is thought probable that the machinery on this side was installed at a later date than that on the other.

The large driving wheel in each case is wedge-keyed to the squared end of the boring bar which is supported in a bearing at each end. Mounted on the bar and rotating with it is the cutter-head which is fed forward through the cylinder by means of a rod passing down the centre of the hollow bar and attached to the head through a longitudinal slot. The other end of this rod is prevented from rotating by a cross bar resting on two wooden beams and is attached to a rack. Rate of feed is governed by a weighted lever acting through a pinion engaging with the rack. The cylinders are supported in heavy timber cradles and are secured with chains.

It is not definitely known how the cylinders were inserted and removed, but it has been assumed that they were slid over the ends of the boring bars. To make this possible the wooden members carrying the outer bearings of the bars have been made removable, and the cross bars made detachable from the feed rods.

The Bersham Works were founded in 1775 and closed in 1795. The larger of the two bars, measuring approximately 15 ft long by 12 in diameter is preserved in the Museum (see **140**).

The model has been designed from the plan of the Bersham boring mill made by John Gilpin and preserved in the Boulton and Watt Collection in the Birmingham Reference Library (a copy is exhibited with the model) and from a consideration of contemporary practice in the construction of gearwheels, waterwheels and machine details as exemplified by the Carron boring mill, drawings of which are given in Smeaton's reports, and from various other sources. It may be assumed therefore that the plan of the model represents the Bersham mill as accurately as can be ascertained, and that all elevations not governed by the plan represent the actual mill in character though they may differ from it, more or less, in detail.

140 Boring-bar

This boring-bar is believed to be one of those installed at the Bersham Ironworks by John Wilkinson in 1775 (see **139**). When these works were closed, in 1795, the bar was bought by Messrs Rigby of Hawarden, from whom it was purchased by the donors about 1854.

The bar is now 11$\frac{7}{8}$ in diameter and 14 ft 11 in long between the bearings, and has a central hole though it, 4 in diameter. A slot, 1$\frac{1}{2}$ in wide, extends throughout the length and passes right through to the bore. A sliding sleeve fits on the bar and on this the cutter heads were mounted. Originally the sleeve was fed along by a rack bar, as shown on the Bersham drawing, but, at some time before 1854, a central feed screw, 2$\frac{1}{2}$ in diameter, was fitted, which passes through a nut bolted to a large key passing through the slot in the bar into a corresponding slot in the sleeve. The bar was also re-turned at the same time.

The screw has a right-hand square thread with two turns per inch and is carried in bearings at each end; it is secured by a collar at the driving end of the bar. At the opposite end of the bar the screw carries a loose spur-wheel with 63 teeth and having clutch dogs on its outer face, which may be engaged with corresponding dogs on a sliding hand wheel keyed on the end of the screw. This wheel engages with a 60-tooth wheel mounted loosely on a fixed countershaft, and a 63-tooth wheel, fixed to the other, gears with a 60-tooth wheel fixed on the end of the boring bar. Thus, when the dog clutch is engaged and the loose wheel keyed to the screw, then as the bar revolves once, the screw revolves about 0·09 turn relatively backwards, thus pushing the cutter head along the bar. When the clutch is disengaged, the sleeve may be traversed by the hand wheel. The drive from the nut is transmitted to the sleeve by a head on the key, the latter being fixed to the sleeve by a set screw and a cotter. The nut is inserted through an enlarged part of the slot near one end.

The bar is now mounted on two cast-iron pedestals with lower brasses only, but these are probably more modern. It was driven by a large carrier keyed on its end.

141 Drawing of a Cylinder Boring Mill 1795

Scale 1 : 36

This drawing, 22 in by 20 in, copied from the original in the Free Reference Library, Birmingham, represents the cylinder boring machine designed in 1795 by Peter Ewart for Boulton and Watt's new Soho Foundry, but not actually constructed. In the event a horizontal mill was built.

From 1776 until 1795, Watt's cylinders were cast and bored by John Wilkinson at Bersham Ironworks (see **139**). James Watt, Junr, writing to Matthew Boulton in June 8, 1795, said: 'Inclosed you have Mr Peter Ewart's plan for perpendicular boring, which I address to you as the advocate of that mode of operating.'

The proposed mill has a solid vertical boring bar, 12 in diameter, and 14 ft 6 in long, supported by a timber framing which is housed in a masonry pit. It is rotated by a large spur wheel at its lower end, driven by an inclined shaft and bevel gearing from a horizontal shaft at the ground level. The sliding cutter head has a longitudinal keyway, and the feed is obtained by two racks attached to a loose ring on the cutter head, raised by pinions on a transverse shaft at the top of the machine. The cylinder is suspended by its upper flange from transverse timbers and secured laterally by two sets of four struts with adjusting screws.

A cylinder 28 in diameter and 7 ft 3 in long is shown in position.

142 Model of a Vertical Cylinder-boring Mill 1838

Scale 1 : 12

This model represents a machine for boring large cylinders, such as marine-engine cylinders, which was erected at HM Dockyard, Woolwich, by Nasmyth, Gaskell & Co. The model is based on the design by James Nasmyth in Robertson Buchanan's *Mill Work* (1841).

The vertical arrangement has the advantage over the horizontal type of machine that distortion of the cylinder and the boring bar due to their weight is avoided; the cutters are kept clear of borings, since they fall to the bottom of the cylinder; and the machine occupies less floor space. A vertical machine had been proposed by Peter Ewart (**141**) and a similar machine was patented and constructed by Michael Billingsley in 1802. The screw feed is said to have been introduced in Boulton and Watt's Soho Foundry about 1800 and has been ascribed to William Murdock and to George Wright.

The machine is built into the corner of the shop and the upper centre of the boring bar is mounted in a diagonal girder bolted to brackets in the walls.

Power is applied through a worm shaft to the driving pinion which is situated in a pit, and the weight of the boring bar is supported by two hardened steel discs running in oil in the lower bearing. The bar is steadied in its rotation by a bearing above ground level. The cutter wheel is keyed to a slot in the bar so that it can slide up and down.

The cylinder casting, 6 ft in diameter and 9 ft 10½ in long, is clamped to stands on the floor. The boring bar, 16 in diameter and 15 ft 10 in long, has a screw within it, which passes through a nut in the cutter wheel. This screw is rotated very slowly by the sun and planet motion of the gear train mounted on the top of the boring bar and meshing with a pinion fixed to the girder, so that the cutter slowly descends as it revolves.

The machine is constructed so that it may easily be disassembled after making a cut; the parts being handled by a small crane mounted above it.

143 Drilling and Slotting Machine

These two machines are built back to back and share the same cast-iron column as their chief structural element. Both machines were belt driven from overhead shafting.

These machines come from the workshop of Strutt and Arkwright's Mill at Milford and were used in the construction of cotton machinery in the early nineteenth century. If the machine was part of the original equipment of the shop, it could be as early as 1817; but as the invention of the slotting machine is attributed to Richard Roberts (**159**), who set up his own workshop only in 1817, the date of this machine must be presumed to be later.

144 Hand Drilling Machine, early nineteenth century

The mechanism of this small drilling machine is supported on three upright iron rods screwed into a circular wooden base. The spindle is driven by means of a handle through brass bevel gears which increase the spindle speed by approximately 2 : 1. The spindle and gears are mounted in a frame which may be raised or lowered by a hinged lever with wooden handle. This provides the feed and allows the drill a movement of one inch.

145 Drilling Machine c. 1840

(*See plate 13*)

This machine, which was formerly the property of James Nasmyth, resembles the large power drills constructed by the firm of Nasmyth, Gaskell & Co about 1840.

The framing consists of a base with two columns supporting a cross girder which carries the drill spindle and its driving and feeding arrangements. The power is transmitted through mitre wheels to the drill spindle, which is fed downwards by a central screw supported by a crosshead carried on two small wrought-iron columns. This screw is fitted with a winch handle for feeding it downwards by hand; there is also an automatic feed given by a vertical shaft that is intermittently rotated by a pawl worked by an eccentric on the lower end of the spindle sleeve. In the larger machines stepped driving pulleys were used, also an independent work table, with horizontal screw adjustment in two directions.

146 Self-acting Drilling Machine 1846

This drilling machine was made by J. Whitworth & Co and is fitted with the self-acting feed motion patented by Sir Joseph Whitworth in 1837.

The spindle is driven by bevel gearing in the usual manner; it has a screw thread cut on its upper part which gears with two worm wheels mounted on and keyed to transverse shafts. To the outer ends of the shafts friction rollers are fixed, fitted with brake blocks which are drawn together by a rod with right and left-hand screw threads. When the drill spindle revolves the worm wheels are rotated by the screw, but when the rollers are gripped by the brake blocks, the worm wheels are retarded and caused to act as a nut by means of which the spindle is advanced. A hand wheel on one of the transverse shafts is provided for rapidly withdrawing the drill, which it does by using the screw as a rack. The table is provided with T slots and can be both rotated and moved transversely.

147 Drilling Machine for Watch Plates 1848

This machine, patented by Richard Roberts in 1848 as a 'normal' drill, is an arrangement for drilling to a template a large number of holes in the frame plates of clocks and watches.

The drill spindle is carried on a rigid bar, and on this bar also is a frame that carries the guide pin or stop. Parallel to the fixed bar is a similar bar supported on trunnions and provided with a counter-balance weight; on this bar are clamped two headstocks connected together by an intermediate spur-wheel. The headstock nearest the trunnion carries a chuck which holds the frame that it to be drilled, while the outer headstock carries a plate that has been drilled with uniform holes into which the guide pin will fit. This template is an enlarged pattern of the frame to be drilled, the ratio of enlargement being determined by the position of the two chucks on the swinging bar, which is graduated for their correct adjustment. On one of the templates shown the pitch circles of the train to be drilled for are still visible.

148 Model of Slot Drilling Machine 1855

Scale 1 : 4

This machine was patented by T. B. Sharp and R. Furnival for cutting elongated holes by means of a revolving tool, somewhat resembling a drill, slowly travelling to and fro over the length of the required slot.

The machine has a box bed supported on standards with an adjustable table projecting in front to carry the work, which remains stationary during the operation. The overhanging drill headstock slides along the top of the bed and the rotary motion is transmitted to the tool by gearing from a longitudinal feather shaft. The longitudinal reciprocating motion of the headstock is obtained from an adjustable horizontal crank and connecting rod, which drive a screwed spindle passing through a nut on the under side of the head, so that both the length and position of the slot can be adjusted. The crank motion is worked from a countershaft below the bed, driven by a belt from the upper shaft, which drives the crank by worm gear and an eccentric pinion gearing with an elliptical wheel on the crank disc. In this way the angular velocity of the crank is varied so as to render the traversing motion of the drill fairly uniform. The intermittent vertical feed motion to the drill is transmitted through a friction clutch and worm gear from a ratchet wheel actuated by a cam on the crank disc. When the clutch is released the drill can be raised or lowered by hand. A continuous vertical feed, used for ordinary drilling, is provided by worm gear through another clutch driven by a belt from the upper shaft.

149 Watchmakers' Drill Turns

These are two specimens of drilling machines sometimes used by watch and clockmakers and driven by small bows.

One has a forked frame with a lug at the bottom for holding it in the vice; one end of the fork is tapped to receive an adjustable back centre and the other has a plain hole through it. The spindle has a shouldered fore-end fitting the hole, while the back centre holds the shoulder up against the bearing. The nose of the spindle is bored for the reception of the drills, and it carries a pulley at its rear end for the bow string to act upon.

The other specimen has a solid brass head with a plain bearing hole in which the spindle runs. The back end of the spindle carries the driving pulley, and the front end is formed as a split chuck for holding the drills. The spindle is held in position by a pin which engages with a groove in it. A bow for use with these turns is also shown, it is of whale bone and has a fine gut band.

150 Adjustable Reamer

This is a form of adjustable reamer patented by W. J. Smith in 1910; it is intended for both roughing and finishing cuts, the blades being either of high-speed or of carbon steel.

The reamer consists of a mild steel shell slotted and recessed to receive six blades which fit on a hardened steel conical bolt housed within the shell. The outside of the shell is fluted between the blades, which are well backed up while having their cutting edges clear. The middle portion of the coned bolt is turned parallel, screwed and fitted with a nut that is prevented from turning. The lower and larger end of the cone can be rotated by a key, this action causing the cone to travel endwise, thus pushing the blades radially outwards and increasing the diameter of the reamer. The end of the cone is graduated in divisions, each of which represents a variation in diameter of 0·00025 in. The maximum diameter is $1\frac{11}{16}$ in. The blades are cut away to clear the internal nut and they are locked by being gripped between this nut and the shell by means of another nut threaded on the small end of the bolt. The top of the shell is recessed to receive the key of the arbor on which it is mounted. The blades can be re-ground by placing the reamer in a grinding machine.

151 Jig-boring Machine 1921

(*See plate 23*)

The jig-borer is a very accurately made and extremely rigid machine tool intended for the exact location and boring of holes and is suitable for use in making jigs and dies. The drilling head is mounted on a cross beam spanning the table and supported by columns in the manner of a planing machine. The head is capable of being traversed along the bridge and the table can be moved at right angles to this direction.

This machine has a capacity of 18 in by 24 in and weighs about 2 tons. The precision of a jig-boring machine is such that it should be kept in an air-conditioned room at constant temperature.

The jig-borer originated from the pointing machine made in 1912 by the Société Genevoise d'Instruments de Physique, at Geneva, for marking out watch plates. This led to the design of the industrial jig-borer of which this, the first made by the company, was built in 1921 for the Royal Small Arms Factory at Enfield. In the meantime the Pratt and Whitney Company had brought out a jig-boring machine in 1917.

The lateral movement of the boring head and the movement of the table are controlled by lead-screws, set by micrometer drums. A pitch-correcting device rotates the vernier sector, by which the setting of the micrometer drum is made, by an amount which eliminates the error at the position in which the table or the head is being set. The amount of rotation is determined by a lever, in the ratio 200:1, in contact with a metal template. The template was made for each lead-screw in terms of a high precision scale read with a microscope at one centimetre intervals. The guide ways of the bed are slightly convex in order to correct for the deflection produced by the weight of the table.

152 Expanding Boring Tool 1920

This tool-holder is provided with an arrangement which enables the cutting tools to be moved outwards simultaneously and by an equal amount, when it is required to increase the diameter of the hole being bored.

The cutting tools are held in inclined holes in the flanges of two sleeves which are pressed together to hold the tools by means of an end nut. Their ends are chamfered and abut against the chamfered ends of two plungers whose axes are at right angles to the axes of the tools. The plungers are operated by a screwed ring and on this being rotated they press the cutting tools outwards, thereby increasing the cutting diameter. The tool-holder is arranged to be driven by a cutter from a boring bar and is locked in place longitudinally by a sunk grub screw.

153 Bench Type Drilling Machine 1925

The drilling spindle is driven through a pair of three-cone pulleys by means of an electric motor of $\frac{3}{8}$ hp, which runs at 1,900 rpm. Feed is by hand through rack and pinion, the spindle being automatically lifted by a coiled spring when the handle is released. An adjustable stop is fitted on the upper part of the spindle. The spindle as well as the armature shaft run in ball bearings and all parts are accurately balanced.

The machine will drill holes up to $\frac{1}{2}$ in diameter and will accommodate objects 10 in high.

154 Ultrasonic Drill 1957

In this drilling machine the cutting tool is reciprocated at the ultrasonic frequency of 20 kc/s and the cutting is due to the chipping action of the abrasive particles which are applied as a slurry to the tip of the tool. As the tool is not rotated, non-circular holes may be cut.

The drill head consists of a magnetostrictive transducer coupled to a brass matching stub to the end of which are screwed the various cutting tools. The power is supplied by a 50 watt oscillator.

The machine is suitable for the drilling of hard and brittle materials such as glass and ceramics.

Planing Machines

See also **239**

155 Planing Machine 1817

(*See plate 25*)

This machine, made by Richard Roberts in 1817, is believed to be the earliest planer now in existence and one of the first made for planing metal. It is evident from the marks of chisel and file on the bed that it was itself made without the use of a similar appliance.

In general design the machine bears a strong resemblance to the modern planer. The work is bolted to a table which moves to and fro on a straight bed, under a fixed tool which is capable of being traversed so that, by the two motions, plane surfaces are produced as the tool makes successive cuts. The table is mounted on one side on a narrow flat face and on the other on an inverted V and is hand operated by means of a chain and drum. The cross slide is supported on two standards bolted to the bed and is provided with vertical adjustments by two screws which are not however interconnected. It has an internal screw for traversing the tool rest which is capable of angular movement and is fitted with a separate hand feed motion for the head. The tool is held in a hinged clamp which allows it to lift on the return stroke. The table is 52 in long and 11 in wide.

156 Planing Machine 1842

(*See plate 26*)

This power-driven self-acting planing machine, made by Joseph Whitworth & Co, was patented in 1835-9 by Sir Joseph Whitworth and was known in the shops as a 'Jim Crow' because of its reversing tool holder. The expression derived from a popular song, brought out in 1836, which contained the lines:

> 'Wheel about, and turn about, and do just so;
> And every time you wheel about, jump Jim Crow.'

A lead-screw in the middle of the bed of the machine, driven by fast and loose pulleys and a three-bevel-wheel reversing arrangement, transmits motion to the V-guided table by means of a pair of antifriction wheels on its underside, mounted on studs perpendicular to the axis of the screw, with the thread of which their rims engage. The cross-slide is supported on and is actuated by two vertical screws connected by bevel gear and shaft which is hand-operated. The swivelling tool-box is on a screw on the cross-slide and is fed by a ratchet and pulley. The latter is actuated by a band from a rocking pulley on the same shaft as a pinion moved by a rack rod alongside the bed. This rod is moved to and fro by the table coming against stops. By means of guide-pulleys, the band also reverses the tool holder at the end of each stroke, thus enabling it to cut in both directions. The bed of the machine is 4 ft by 15 in; the maximum height under the tool is 12 in.

157 Planing Machine 1857

This small machine, which was formerly the property of James Nasmyth, was built by J. Nasmyth & Co, and in its arrangement and detail it is almost identical with some of the larger machines made by them about 1840. At that time the firm was also making rack-moved planing machines with quick return motions, but for sizes up to 3·5 ft wide by 8 ft travel the gear shown was considered to give a quieter and quicker action.

The frame is a somewhat massive casting, with two V-guides with the apex uppermost. The two standards are bolted to the main framing and are connected by a cross girder which carries a central screw by which the height of the cross slide is adjusted; the cross slide has an internal traversing screw, for moving the tool rest which is capable of angular adjustment and has a hand-feed motion. The tool holder has the usual hinged box for preventing damage to the tool in the return stroke.

The table of the machine is a single casting, with slides planed on its lower surface corresponding with the fixed guides; the upper part of the table has six longitudinal T-headed grooves for receiving the bolts for securing the work. The table is moved to and fro by a mangle-wheel motion, there being two chains passing from the lower side of the table over fixed guide pulleys down to a chain wheel, round which they pass in opposite directions before being secured. The shaft of this wheel carries at one extremity a wheel with lantern pins, or teeth, into which a small pinion on the driving shaft gears. The pinion end of this shaft is carried in a sliding bearing, so that the pinion gears alternately inside and outside of the segmental lantern wheel, thus reversing the motion after a definite length of travel has been effected. The length of stroke can be altered by changing the number of mangle-wheel teeth, which are single pins secured by nuts. In the machine shown, a hand-driving mechanism has been added and the loose pulley removed. The transverse travel of the tool box is automatically given by a pawl feed, receiving its motion from the lateral play of the pinion shaft.

158 Specimens of Curved Planing

The two bronze specimens of helical planing, with pitches of 11 and 37 in respectively, were prepared on an ordinary planing machine, with the work held in a headstock, which made a partial revolution during the travel of the table. They were acquired from Richard Roberts in 1860.

The other specimen is a reed moulding cut in cast iron, to a circular arc. It was done on an ordinary planing machine, on the table of which was placed a second table, or sector, centred on a stud attached to the stationary bed. The sector was attached by two chains to eyes secured to the table, which by its motion caused the sector to swing horizontally; the work was secured to the sector at a distance from the stud corresponding with the radius required.

Shaping, Mortising and Slotting Machines

See also **143, 180, 219, & 239**

159 Slotting Machine c.1835

This machine was manufactured by Sharp, Roberts and Company of Manchester and was used for cutting the keyways in waggon wheels for the Manchester and Liverpool Railway.

The slotting bar is mounted vertically in a cast-iron frame and obtains a reciprocating motion from a connecting rod and crank wheel on the spindle which carries the flywheel and driving pulley. The crank pin is secured in a groove in the crank wheel and may be adjusted to give any stroke up to 6 in.

The table which holds the work may be rotated and may be moved horizontally in slides. The latter motion was originally self-acting, but the ratchet wheel and pawl are now missing. The table frame may also be adjusted vertically and slides between Vs on the inside of the frame standards.

The introduction of a machine for key-grooving was attributed to Richard Roberts by both Nasmyth and Holtzapffel. It obviously derives from Brunel's mortising machine (**219**).

160 Shaping Machine c.1850

(*See plate 24*)

This small bench machine, for working by hand, came from the private workshop of James Nasmyth. The shaper was invented by Nasmyth in 1836 and was, for a time, known as Nasmyth's Steam Arm.

The driving shaft terminates in a disc in which is a slot carrying an adjustable crank pin, by which the length of the stroke can be varied. This pin is fitted with a block capable of sliding in a vertical slot formed on a horizontal ram that carries the tool box; the ram works in adjustable V-guides, and is fitted with a vertical slide in which the tool box is fed by hand. The work-table slides on guides on the front of the main casting and is traversed by an internal screw driven by hand power, or automatically by a pawl feed motion rocked by an eccentric on the main shaft. The table is fitted with a vice, and there is also an arrangement for holding square and hexagonal nuts while being shaped.

161 Shaping Attachment c.1858

This small-shaping attachment, made by Joseph Whitworth & Co, is arranged for mounting on the bed of a lathe.

The shaping head is reciprocated in a V slide on the baseplate by means of a connecting rod and crank, which is driven through reduction gearing from a four-step cone pulley. A slot in the head enables the head to be moved forwards or backwards irrespective of the position of the crank pin, for positioning the tool over the work. The traverse of the tool is adjusted by varying the eccentricity of the crank pin.

The tool box has a vertical feed and the tool is supported in the usual hinged tool holder to prevent damage to the cutting edge during the return stroke. There is no provision for a quick return, the cutting and return strokes taking place at the same speed.

162 Mortising Machine 1860

The chisel is controlled by vertical guides and is forced downwards by the action of a foot lever, the return upward movement being given by a helical spring; the wood to be mortised is held in a vice secured to the machine frame. By means of a screw thread in the top of the tool holder, it is made to rotate through one quarter of a circle in the last part of its ascent, and through another quarter in commencing its descent, so that it turns half round after each stroke.

163 Mortising Machine c.1885

This machine by S. Worssam & Co is an intermediate type between the wooden-framed machine of 1860 (**162**) and the modern machine with chain and hollow chisel.

The work is clamped on a sliding table, and the chisel is mounted in a vertical spindle which is driven downwards for cutting by an overhead hand lever. The chisel can be reversed as required by a pair of mitre gears rotated by hand, the spindle being positioned by a catch engaging with slots on the upper face of the spindle mitre gear. The spindle is counterbalanced by weights on the hand lever. The machine can also be used for drilling.

164 Mortise Chain and Guide Bar 1911

The chain cutter used in a wood-mortising machine, produces a finished mortise of exact size rapidly and in one cut.

The chain is built up of a number of hardened tool-steel link plates connected together by rivets which are countersunk into the outer plates. A cutting tooth, having the proper cutting angle and clearance, projects from one edge of each plate. The smaller chains have alternately one and two plates in each link while the larger sizes have two and three, the thickness of the plates varying according to the total width of mortise required. The guide bar is also of hardened steel and has a ridge on each edge to guide the chain, while a roller bearing wheel at the lower end receives the working thrust. Its upper end is bolted to the slide of the machine, and above it is mounted the driving sprocket.

Milling Machines

See also **75, 133, 170-179, 212, 224, 225, 239,** & **242**

165 Milling Cutter, eighteenth century

This is a replica of a milling cutter made by the French mechanic Jacques de Vaucanson (1709-1782).

The teeth are so fine that it partakes more of the nature of a circular file or rasp, which was no doubt the inspiration of the milling cutter.

166 Rosette Forming Machine

This machine was used for many years by Holtzapffel & Co for making rosettes for their ornamental turning lathes. By the use of various combinations of gears and cams a very large number of different contours may be produced.

The rosette is secured to the nose of a headstock which is slowly rotated through a train of gears and which can be swung through an angle of 90° for cutting on either the edge or the face of the rosette. The other end of the train drives the vertical spindle No 1 carrying a forming cam, which is in contact with a long lever pivoted near one end and held against the cam by a spring. This lever operates the transverse slide of the cutter frame. It will thus be seen that, as the rosette rotates, the cutter moves inwards and outwards at a speed and in a manner determined by the train of gears employed and the shape of the forming cam. These two quantities, each of which can be varied, determine the general character of the design.

A further variation may be introduced by altering the amplitude of the cutter's transverse movement by shifting the fulcrum of the lever nearer to or farther from the cam, thus making the waves on the rosette shallower or deeper.

Provision is also made for forming 'flats' on the rosette by suspending the transverse movement of the cutter during a part of the revolution of the rosette, or at intervals during its revolution. This is accomplished by means of the vertical spindle No 2 on which are mounted two cams, one at the lower end which forces the lever clear of the forming cam on spindle No 1 and another at the top which then lifts the lever onto a plain circular ring mounted above the forming cam.

Yet another variation may be added by using a second forming cam above the first on spindle No 1 in place of the ring and thus two designs may be cut successively on the rosette, the amount of arc occupied by each depending on the shapes of the cams on spindle No 2.

The cutter frame is provided with longitudinal to-and-fro movement in order to take the cutting edges across the face of the work.

The machine was the only one of its kind constructed and was built largely of parts adapted from other machines.

167 Universal Milling Machine 1865

(*See plate 28*)

The universal milling machine was invented by Joseph R. Brown in 1861 for machining the grooves of twist drills. The number 1 machine manufactured by the Brown and Sharpe Company was the subject of patents granted in 1862 and 1865. This is one of the five number 1 machines which were sold in Great Britain.

The main arbor runs in the upper part of the hollow cast frame, upon the front of which is a knee fitted to slide. The knee is adjustable on a screw operated by a crank acting through bevel gears. Another screw to the rear passes through the knee and has on it a nut which serves as an adjustable stop. On the knee is a horizontal adjustable slide, and on this a turntable which holds a long carriage. The latter is moved by a screw which can be adjusted by a handle and also driven through bevel gears and a shaft from the feed cone. The shaft is made in two parts, one of which slides into the other, and has universal joints at each end ; so that the carriage can be set at an angle or adjusted vertically and still be fed at a rate in definite relationship to the spindle speed.

Two centres are fitted in a groove in the carriage. The arbor in the headstock can be connected with the lead-screw of the carriage through a train of gears. When this is done the arbor revolves as the carriage advances, so that the work held in the chuck is given a helical motion. The headstock can also be set at an angle and an index is provided. The head is thus capable of five-axis adjustment: X, Y, Z, and two rotations. This highly original design set the pattern for future milling machines.

One of Brown's drawings for this machine is reproduced on the cover.

168 Straddle Milling Cutters c.1860

These hand-made milling cutters were probably made for use on a mandrel in a lathe. The work mounted on the cross slide would be passed between them. The teeth are not radial but 'behind centre', and therefore give a shearing action.

The only way in which cutters could be sharpened at the time these were made, was by softening, filing, and re-hardening.

169 Vertical Spindle Moulding Machine 1928

A vertical spindle is mounted in ball bearings and driven at a high-speed by a belt drive. The upper end of the spindle terminates in a four-sided block, with slots for T-headed bolts, by which the fly-cutter blades are attached. The cutter head is detachable so that sets of heads with adjusted cutters can be kept in store and rapidly substituted on the spindle when required.

The wood to be moulded is first machine-planed and thicknessed to the correct dimensions and is then hand fed through the moulder, four adjustable springs being provided to hold it firmly in contact both with the table and with the guide. The formed cutters rotating at a high-speed produce the section desired.

Gear-Cutting Machines

See also **239**

170 Wheel-cutting Machine, seventeenth century

(*See plate 18*)

The earliest method of manufacturing clock wheels was to mark off the blank by means of a radial ruler, pivoted at the centre of a plate divided concentrically in numbers of teeth in common use; the teeth were then filed out by hand. In 1672 Robert Hooke, FRS, mounted the divided plate so that it could be rotated, added an index, and applied a revolving file or milling cutter to the edge of the blank.

In this machine the dividing wheel is inscribed with 25 concentric circles divided for cutting wheels with from 31 to 78 teeth with some exceptions. The underside of the plate is inscribed with the name of the maker, Humphrey Marsh de Highworth, and with an unfinished Gunter's quadrant and a perpetual calendar. From the leap years given it is evident that the calendar was begun between the years 1668 and 1672. The work on the quadrant was however abandoned and the brass circle used to make the present machine presumably about the time of Hooke's machine.

The circular plate is attached to a spindle, which carries the blank. The spindle passes through a T plate, the ends of which are slotted and secured by lock nuts to the iron frame and which can be adjusted by a screw to take blanks of different sizes. The cutter is mounted in a frame on bearings so that it can be swung into the blank as the cutting proceeds. The cutter is driven by a handle through gearing.

171 Wheel-cutting Machine, eighteenth century

Various improvements in the wheel-cutting machine took place in the eighteenth century. The tool, in the form shown, known as the Lancashire pattern, is due to John Wyke (1720-1787), of Prescot, a seat of the watch industry from early times.

A circular plate, divided for 55, 60, 63, 64, 70, 72, 75, 80, and 100 teeth, with an adjustable spring index is mounted on a spindle in a cone bearing below and a split collar above, in a cast-iron frame on three legs. On this spindle the wheel blank to be cut is clamped. The cutter is on a spindle driven by gut band mounted in a frame that can be swung out of the way while the blank is being set for a fresh tooth. The bearings of this frame can be slightly tilted so that the skew teeth can be cut. The whole is adjustable by a screw in V-guides on the frame, to admit blanks of different sizes.

172 Wheel-cutting Machine 1789

This machine, for cutting the wheels of clocks, is stated to have been made in Madrid by Manuel Gutierrez.

The blank wheel having been prepared, the spaces between the teeth are cut by a disc 0·6 in diameter, with its formed edge scored by a graver so that it acts as a fine milling cutter. This cutter is fixed on a spindle rotated by spur gearing, from a hand-driven counter-shaft carried between centres on a frame that swings between stops, but is secured in an adjustable slide that permits of skew teeth being cut. This head is carried on a slide so that it can be set to suit the diameter of wheel required and there is a screw feed for adjusting the depth of tooth.

The wheel blank is secured to a vertical spindle, which carries near its lower end a disc 5·9 in diameter, extensively divided on both faces, wheels of even 47, 49, 51, and 58 teeth being provided for. The upper end of this spindle runs in a conical bush and the lower one on a cone centre.

173 Clock Wheel Cutters

These cutters and examples of work illustrate three types of cutter. The single-tooth cutter is made from bar stock. A disc is parted off and bored eccentrically. The edge is then turned to the profile required and a sector is cut out thus producing a single tooth. By making the cut at the point of greatest distance from the centre of the hole a relief is produced and clearance is maintained after sharpening.

In the second type of cutter, invented about a century ago, a disc is turned to correct profile and several teeth made by removing material. The teeth are then undercut and squeezed in to produce relief.

The modern cutter is produced on a special relieving lathe.

174 Rounding-up Tool

This machine is used for correcting the tooth form of watch wheels.

The wheel is mounted between vertical centres so as to be free to rotate. The cutter is mounted horizontally and the pulley on the arbor is driven at a fair speed by a band which passes over a hand wheel.

In place of the usual milling cutter there is one with many cutting points which however extend only two thirds round the circumference, the gap being occupied by a guide which is offset at one end by the pitch of the wheel. The latter is thus rotated after each cut enough for the cutter to enter the next space.

175 Gear Cutters 1839

These four circular steel cutters are examples of the milling tools patented by J. G. Bodmer in 1839 for cutting the teeth of small spur-wheels, racks, etc. The cutters have teeth very similar to those of a saw or a file, but shaped to the profile of the spaces between the teeth of the wheel to be cut.

176 Worm Gear Cutters c.1839

These four milling cutters are examples of the cutter or hob for cutting worm wheels, which was patented in 1839 by J. G. Bodmer.

The hob is identical in outline with the worm with which the required wheel is to work. The worm wheel and the cutting worm are rotated at their correct relative speeds and fed into one another. The hob then excavates the spaces required for the threads of the actual worm to engage in.

177 Collier Gear Cutting Machine c.1850

The blank is carried on the spindle of a dividing wheel mounted on a carriage sliding between vertical guides. The wheel, which has 240 teeth, is driven by a worm geared down in the ratio 2 : 1, and finally set by the handle engaging in a notched plate with 12 divisions. Provision is made for changing the intermediate gear ratio. The cutter is mounted on a horizontal slide bolted to the front of the frame. An adjustable stop is provided to support the blank near the point of cutting to prevent it from flexing.

The original worm wheel was replaced by J. Whitworth & Co in the 1880's and the cutters date from the last 15 years of the nineteenth century.

178 Formed Gear-tooth Cutter, 1928

In this type of gear-tooth cutter, which was originally patented in 1864 by J. R. Brown, the teeth are formed and backed off in such a manner that when ground on a line radial to the centre, or in some cases a line forming a tangent to a circle about the centre, the cutter shape is not changed, whilst the backing off permits the cutting edge to be presented to the work with the correct rake and clearance angle.

Because of this method of formation the cutter may be repeatedly re-sharpened until the cutting teeth are reduced to a thickness too fragile to withstand the cutting pressure, thus ensuring maximum economy in cutter usage. All tooth and profile forming cutters at the present time are made on this system.

179 Gear Cutter c.1875

This cutter was made between 1870 and 1880 by R. W. Munroe and is a good example of the craftsmanship of the early engineers.

The blanks were turned and the profile and relief cut with a chisel, filed to a template and finished by hand grinding. The form of the tooth is cycloidal. In order to maintain the width of the tooth, which, due to the relief, is reduced by re-grinding, the cutter is made in two halves so that it may be packed with paper washers.

180 Robey-Smith Bevel Gear Cutting Machine

(*See plate 19*)

This is the original experimental machine invented by Mr J. Buck in 1895. It illustrates an early stage in the development of the planing or shaping type of gear cutter subsequent to the application of the simple shaping machine to such work and was the first machine in which both sides of the tooth were cut simultaneously. The tooth curve is an arc of a circle, generated upon the principle of the odontograph and is a circular approximation to the involute.

The blank to be cut is placed upon the spindle which carries an index plate corresponding to the number of teeth required, the whole being mounted on a saddle which is pivoted about an axis representing the apex of the cone. The blank is fed to the cutters by swinging this saddle about the pivot.

The two cutting tools and tool holders are reciprocated simultaneously by crank motions and the tool slides are pivoted about an axis enabling the cutting edges of the tools to move on lines which converge at the apex of the pitch cone as viewed in slide elevation. After each stroke of the cutting tools the gear blank is indexed round one tooth-space, so that after cuts have been taken along the sides of one tooth the next stroke will make cuts along the side of the next adjacent tooth and so on round the blank. After a complete revolution of the blank the saddle is fed towards the tools for a further series of cuts. In order to generate the tooth-form a parallel motion by a disc with suitably developed slots engaging pins on the extremities of the tool slides is provided to separate the cutter slides gradually in proportion to the depth of cut taken into the blank.

The curvature of the flanks of the teeth depends upon the ratio existing between the rate of separation of the tool slides and the feed of the tools into the blank.

A pair of gears cut on a later version of the Robey-Smith bevel gear planer and a pair of gears cut on a machine developed from it, the Smith & Coventry spiral bevel gear planer, are also exhibited.

181 Bevel Gear Generating Machine 1901

The first machine to use a reciprocating rack-tooth cutter on the moulding-generating principle was invented by Hugo Bilgram in 1884 to produce bevel gears. The machine in the Collection is the automatic version introduced by Bilgram in 1901.

The machine is basically a shaper, but the gear-blank is given a rolling motion in relation to the reciprocating cutter. The gear-blank carrier swings about a vertical axis and at the same time causes the blank to rotate. This latter motion is brought about by means of a pair of steel bands attached to the frame and also attached to and wrapped about a portion of a conical surface on the axis of the blank. The apex of the cone lies on the pivotal axis of the carrier.

The resultant motion given to the blank is the same as it would receive if it were rolling in gear with a circular rack. The cutting edge of the tool corresponds to a side of the rack tooth, and its action is to generate on the blank a conjugate tooth which has octoidal form.

The indexing mechanism spaces the teeth, and the feed rotates the blank slightly after each series of cuts.

182 Ducommun Bevel Gear Planing Machine c.1900

This bevel gear planing generating machine has a pair of cutters which reciprocate as in a shaper to cut both sides of the gear blank at once. The necessary rolling movement of the blank is provided by a link motion. The machine is indexed by hand after the cutting of each tooth.

183 Model of Gear Hobbing Machine 1922

This model conforms in general outline, though not in actual scale of certain parts, to the gear hobbing machines manufactured by Henry Wallwork & Co Ltd Manchester.

It is capable of generating spur gears, worm wheels, spiral geats, etc, up to the limit of its capacity for holding blanks.

The machine uses a hob with the teeth formed with straight sides, and set at an angle to the axis of the hob corresponding to the pressure angles of the gears to be generated.

The form of tooth generated is involute, which curve is formed by the combination of the motion of the tooth of the hob, and the rotation of the blank upon which teeth are being generated. In cutting spur gears the helix angle of the hob is brought parallel to the teeth of the spur wheel by setting the cutter head, which can be set to any angle from 0° to 180° by one-minute intervals. When worm wheels are to be generated the axis of the hob is set to the angle at which the worm will mesh with the wheel.

The hob is set for spiral gears so that the helix angle of the hob corresponds with the helix angle of the spiral gears to be cut. Sets of change wheels provide the various ratios for cutting different numbers of teeth and for various feeds. Both feed and counting gears must be calculated to work together in a definite ratio when spiral gears are cut.

Grinding Machines

See also **134** & **239**

184 Diamond Cutting

This print shows the method of cutting and polishing diamonds in use in the middle of the eighteenth century. Little change has taken place in the method up to the present day.

The rough stone was cemented with mastic into a block of wood with a handle by which it was held, by means of a set screw, in a triangular frame so as to act as its third point of support. The lap was a soft steel disc on a vertical spindle with adjustable conical pivots. Three or more of these spindles were supported in a wooden framing with a table at the level of the lap. The spindles were rotated by gut bands from a wooden flywheel with a crank and connecting rod worked by a boy. Two legs of the frame rested on the table and the diamond rested on the lap which was fed with diamond dust mixed with olive oil. Pressure might be put on by loading the frame with leaden weights.

185 Model of Double Grindstones 1858

Scale 1 : 4

This unusual arrangement of workshop grindstones, was patented by William Muir in 1853, with the object of keeping the grindstones true by causing them to rub together.

The stones are mounted on parallel shafts in the same trough in contact with each other, but they are made to revolve at different speeds so that there is a mutual rubbing action between them. To prevent grooving a lateral motion is given to one of the stones by a worm and wheel which operates a cam. As the grindstones wear they are brought nearer together by means of a pair of right and left-handed screws.

186 Emery Wheels 1866

These are samples of composition wheels, patented by David Fisher in 1856, for grinding and sharpening tools. Samples of the composition in the form of bars and rods, to be used as files, are included.

187 Universal Grinding Machine

The universal grinding machine was introduced by the Brown & Sharpe Company in 1875. This is a fairly early example which includes improvements up to 1903. Features of Joseph R. Brown's patent were the swivel table mounted on a reciprocating table and provision for adjusting the relative positions of the head-and-tail stocks and the wheel arbor, so that a great variety of work could be done on the machine.

188 Grinding Machine 1910

This Landis universal grinding machine is capable of external and internal grinding. The grinding wheel travels automatically and dwells at the reversing points to allow the wheel to grind itself clear at shoulders. The wheel also has automatic cross-feed operating at each reversal of the carriage. Both the table and the headstock are able to swivel for grinding tapers.

189 Goniostat

This is a small instrument made by Holtzapffel & Co for the accurate grinding of lathe and other tools.

The tool to be sharpened is placed in a holder which is held by a thumb-screw in an arm pivoted at its lower end to a plate. The upper end of this arm moves across a scale marked in degrees. It may be clamped in any position by a screwed nut and in this way the inclination of the tool in one plane is set. The plate carrying the tool-holder is pivoted at its lower end in a fork in the frame of the instrument, whilst at the upper end a circular arm attached to the frame passes through a slot. This arm is divided in degrees and the frame may be fixed at any inclination at right angles to the first by tightening a thumb-screw. The tool point rests on an oil-stone slab or lapping plate.

190 Saw-sharpening Machine 1912

This is a machine for automatically sharpening small metal-slitting circular saws. It was sold under the name 'Fontaine'.

The grinding wheel rotates in stationary bearings, while the saw is mounted horizontally on a sliding table that receives a reciprocating motion to and from the wheel. The saw is fed round, tooth by tooth, between the grinding strokes, by a spring pawl which receives a rocking motion from a swash plate fitted to a pulley on a short shaft.

Sawing Machines

See also **190, 215, 217, 222, 223, 237, 239, 242,** & **243**

191 Engraving of Etheridge's Pile Sawing Machine 1738

'A Perspective View of the Engine, made use of for Sawing off under Water, the Piles which helped to support the Centres, for turning the Arches of Westminster Bridge. Most humbly inscribed to the Right Honourable etc. The Commissioners for Building the said Bridge—by the Inventor, William Etheridge Carpenter.' Engraving, 17½ in by 14 in.

The saw was held in an iron framework clamped to the pile and operated by means of ropes passing over brass pulleys by two workmen standing on floats.

192 Model of Saw-frame for Ships' Timbers

Scale 1 : 8

This represents an early type of machine which was patented by Sir Samuel Bentham in 1793, for sawing timber into curved, bevelled, or winding forms, as required for the ribs of wooden ships, etc.

The timber to be sawn is fixed in a frame which as it travels along, is moved sideways by means of a pin which travels in a curved slot in the stationary main framing. The movable frame is mounted upon a second frame which is capable of rocking about a horizontal axis, so that the timber may be placed in the right position to be sawn, either with a bevel, or in a twisted or winding form.

193 Samples of Veneer and Small Blocks 1793

These examples were cut by machines patented by Sir Samuel Bentham in 1793.

194 Model of Circular Saw Bench 1864

Scale 1 : 4

The saw, formed from a disc of sheet steel, is clamped by a nut and washer against a flange, provided with a steady pin and solid with the driving shaft. Part of the table lifts out to allow of access to the nut for changing saws. The fence or guide is arranged to traverse on a screw in a slot in the table to allow any width to be cut.

195 Band Saw 1888

(*See plate 27*)

The saw is in the form of an endless band, running over three pulleys, one of which is turned by hand. The ends of the blade are united by brazing and the tension is regulated by altering the position of the uppermost pulley. The table can be tilted for cutting on the bevel.

196 Model of Reciprocating Saw 1890

Scale 1 : 5

This is a model of an early type of machine saw for intricate cutting in metal sheets or plates, several of which may be cut simultaneously.

The machine consists of a planed cast-iron table carrying a heavy double armed bracket which holds the guides for the saw blade both above and below the table. In the bracket are two horizontal levers turning on central gudgeons, one above and one below the table. These levers are connected at one end by the saw blade carried in adjustable straining holders, and at the other by a vertical link and are reciprocated by a connecting rod driven by a stepped pulley. The pulley is formed with a cone clutch, under the control of a treadle and a hand lever, for smoothly starting and stopping.

197 Model of Reciprocating Saw Mill 1902

Scale 1 : 10

The model shows a power frame-saw, made by Messrs F. Arbey & Son, of Paris, in which only one saw blade is used. This blade is carried, in tension, between the overhanging arms of a frame, reciprocated in vertical guides by a connecting-rod from a crank pin on shafting beneath the floor level. The log to be squared or sawn is gripped at one side by two pairs of claws, actuated by screws in two vertical slides or standards. The standards are adjustable across the bed of a carriage which is supported on special rails and moved by a pinion engaging with a long rack. The pinion is rotated continuously through a train of reduction gearing by belt drive for the first motion shaft. A friction clutch controls a quicker and reversed travelling motion for use in running back the carriage. The upper edge of the saw is somewhat in advance of the lower one, so that the teeth shall not drag through the timber in the upper or non-cutting stroke. In oaken timber for depths of from 12 to 28 in the rate of feed for a saw of this period and type was from 8 to 4 in/min, or the area of the surface cut about 100 sq in/min.

198 Model of Circular Saw with Guard 1894

Scale 1 : 4

This model represents a circular saw bench fitted with rollers at each end to facilitate the placing of heavy timber. The usual adjustable fence or guide is fitted, but it has a swivel front, so that timber can be cut on the bevel when desired.

The saw is fitted with a guard, introduced by J. B. Lakeman, one of HM Inspectors of Factories. This is to prevent the possibility of the operator falling against a rotating saw, or being struck by loose pieces of timber carried round by it. It also prevents sawdust being thrown upon him. The guard consists of a curved metal plate, provided at the front end with a flap that may be thrown back when starting to cut deep stuff.

199 Model of Circular Saw with Guard 1902

Scale 1 : 2

This model of a saw bench is fitted with a form of guard, patented in 1898 by A. W. Glover.

The whole of the back portion of the saw is shielded by a closely fitting stationary blade, slightly narrower than the cut made by the saw, so that it does not interfere with the passage of the timber. The front of the saw is guarded by a channel-shaped flap under which the wood to be cut is passed. Both guards are adjustable to suit saws of different diameters and the front guard can be set to suit the thickness of wood being cut. The whole arrangement is carried by a vertical post turning in a bracket secured to the bench, so that it can quickly be removed or swung out of the way when not required.

200 Band Sawing Machine 1925

This type of band sawing machine is suitable for joinery and for cabinet makers' and pattern makers' use.

The saw pulleys in this machine are mounted upon a pillar of heavy box section and run on double row ball bearings arranged with a minimum of overhang. Provision is made both to tilt and line the upper pulley for correcting the running of the saw. The saw is strained and kept at an even tension by means of a device consisting of a lever mounted on knife edges upon which is hung a weight made up in small sections so that it can be varied to suit different widths of saw.

For bevel cutting the table cants 45° to the right and 10° to the left and can be securely clamped in all positions.

Adjustable saw guides are provided above and below the table; the upper guide runs in ball bearings and is counterbalanced by an enclosed spring.

201 Metal-sawing Machine 1935

This power driven metal-cutting saw designed for modern workshop practice has a capacity of 6 in by 6 in. It was sold under the name 'Rapidor'.

The machine embodies several improvements on the earlier type, chief among them being the dash-pot mechanism whereby the pressure on the saw is automatically relieved on the return stroke. This also provides a means of checking the descent during the initial downward movement, thus, allowing the saw, even while moving, to be lowered gently onto the work. An adjustable stop is also provided for automatically stopping the machine at any depth of cut. The vice for holding the work is capable of being swivelled for making angular cuts, and provision is made for starting the cut on sharp corners.

Copying Machines

See also **225**

202 Medallion Lathe, French, c.1760

This is a combined medallion lathe and rose engine with a detachable screw-thread chasing attachment. It is shown set up for medallion turning. The matrix is held in a chuck on the rear end of the headstock spindle and the medallion blank is mounted similarly on the front end. The spindle is able to move longitudinally, but under the influence of a spring is pressed backwards so that the matrix is held in contact with a copying point. Both the copying point and the cutting tool holders are mounted on slides which are caused to move slowly out from the axis of the spindle by flexible wires attached to grooved pulleys. These are rotated by means of a double worm and worm-wheel train enclosed in an oil-retaining case and driven by a round belt from the spindle pulley. The lathe spindle thus moves forwards or backwards as it rotates so that the tool cuts contours on the blank corresponding to those being traced out by the copying point on the surface of the matrix. The high points become low points and vice versa.

For screw cutting and ordinary turning, the machine is provided with a second tool rest, the base of which carries a swivelling slide which can be set for either sliding or surfacing, the tool rest being moved along a rectangular guiding surface by a screw turned by a handle and furnished with two index plates graduated to read to 12 and 18 divisions respectively. The cutting tool is mounted in a smaller dovetailed slide which has a screw-adjusted stop incorporated with the tool holder and can be set for taper turning. When screw cutting, the medallion matrix chuck is removed from the end of the spindle and a short guide screw substituted, the whole spindle being moved endwise when the guide screw is engaged with a threaded segment carried by a detachable bracket. For turning, the spindle is held against longitudinal movement by a plate on the rear spindle support, which engages with a groove in the spindle.

The back shaft and bearings are not original. The equipment of this lathe includes an eccentric chuck.

203 Sculpture Copying Machine

This the proportional sculpturing machine was built, together with **204,** by James Watt during his retirement between 1800 and 1819 and is preserved in his Garret Workshop. A rapidly revolving tool, driven by a gut band from the treadle below, is mounted on a universal jointed arm on which is also mounted a feeler. The original to be copied is mounted on a carriage capable of rotation on its axis and the material to be cut is mounted on a similar carriage. Both original and copy are set at the same angle by means of dividing heads. As the feeler is made to pass over the original the tool cuts a corresponding path on the copy. The feed is obtained by moving the carriages which are connected by a pantograph so that any desired proportion between the two is ensured.

For further information on Watt's sculpturing machines see *The Garret Workshop of James Watt* by H. W. Dickinson, a Science Museum Publication.

204 Sculpture Copying Machine

This machine is generally similar to **203,** but was designed for copying to the same size. The original and work are mounted on vertical centres and rotated together by means of gearing. It is preserved in James Watt's Garret Workshop.

205 Machine for Reproducing Sculpture

This machine for reproducing sculpture upon a reduced scale was made in 1826 by Benjamin Cheverton (see **230**).

The original sculpture and the block of ivory or other material in which a reduced copy is to be made are mounted upon vertical spindles connected together by gearing, so that they can be rotated by hand through equal angles when required. The tracing point and cutting tool are mounted upon a carriage which slides on a bar pivoted on a ball joint. They are interconnected by linkwork which allows them to move together longitudinally, with respect to the bar, for the carving of recesses which would otherwise be inaccessible. It is the provision for this movement which distinguishes the machine from engraving and die-sinking machines and renders it suitable for reproducing sculpture.

The ratio of reduction is varied by moving the tracing point and tool, with their carriage, towards or away from the fulcrum at the ball joint, the position of the spindles carrying the original and copy being adjusted to correspond.

The tool was originally driven through a flexible coupling from a pedal gear.

206 Bust of James Watt

This miniature portrait bust in ivory on a marble column is an example of work carried out on Cheverton's sculpture reproducing machine (**205**). It is a copy to the considerably reduced overall height of 8½ in of the bust executed in 1815 by Sir Francis L. Chantrey, RA, and now in the Ashmolean Museum, Oxford.

207 Engraving Machine

(*See plate 17*)

This machine, for preparing the steel master punches from which the dies for coining are made, was purchased for the Royal Mint in 1824 in Paris. It is an example of the 'tour à portrait' invented by Hulot about 1800.

The machine is in principle a copying lathe, in which the original and the copy are mounted in the same plane, on the ends of parallel horizontal axes which are coupled together and rotated at the same speed. A bar, pivoted at one end on a universal joint, passes in front of these and has mounted upon it a tracing point and a cutting tool, which are set opposite to the centres of the original and the copy respectively. While the medallion and copy are revolving the tool bar is gradually lowered so that the tracing point traverses the surface of the original from the centre to the circumference, moving inwards and outwards as it encounters the various features of it. The cutting tool also traverses the face of the copy, in a similar manner, but the distances moved through, both transversely and horizontally are reduced in the ratio of the distances of the tool and tracer from the pivots of the tool bar, thus producing a reduced copy of the original as nearly like it as the necessary size and shape of the tracer and tool will permit.

The machine has a brass bed, secured to the top of a wooden table, and on this is mounted at the right-hand end a transverse shaft occupying a fixed position and carrying the original. The copy is mounted on a headstock, which carries another shaft at the same height, and slides upon the bed ; it may be secured at any position lengthwise in order to provide for reduction in any desired proportion.

At the right-hand end of the table is a transverse shaft, having at its rear end a toothed wheel which gears with a smaller wheel mounted on the end of the shaft that carries the original. On the front end of this shaft a worm is fitted that engages with a worm wheel fixed to the lower end of a vertical screw, which is held in bearings at its ends ; a nut, threaded on this screw, slides on vertical guides, and has projecting from it a horizontal pin upon which rests a roller mounted on the end of a curved bar forming an extension of the tool bar. Thus, when the lathe is set in motion the original and copy revolve, and this screw, being also rotated, gradually lowers the nut together with the bar, tracer and tool ; the latter are held up to the work by a weight attached to the end of the bar by a cord passing over a pulley fixed to the nut.

The machine is also capable of producing a copy equal in diameter to the original but with reduced relief, and for this purpose, the tool bar pivot is lowered at the same rate as the right-hand end of the bar, by means of similar mechanism.

The medallion used as the original, which is made as large as possible, would be a reproduction of the artist's design, made in a material sufficiently hard to withstand the rubbing of the tracing point. The copy when taken from the machine requires touching up by hand in order to finish those parts which the machine is not able to reproduce exactly.

208 Engraving Machine

This machine, patented in 1866 by C. J. Hill, is similar in principle to **207** and was used for the same purposes. In this machine, however, the shafts are placed vertically, the original and copy eccentrically to the shaft centres, and the engraving tool consists of a small rotating cutter driven at a high-speed by a gut band from a flywheel and treadle.

The tool bar is moved across the work by hand instead of by mechanism, and the rotary motion of the original and copy, which in this case merely gives the feed, is very slow and only covers a small portion of a revolution. The machine is adapted for using originals of large size which have the advantage that any slight defects in them disappear on reduction; also the rotating cutter, the shape of which is similar to that to the tracer and in correct proportion, will produce a more exact copy than the lathe tool. The copy may, moreover, be operated upon locally, the feed and speed of traverse being adjusted so that the tracing point can follow closely the most intricate features of the original, which point chiefly determines the accuracy and finish of the copy.

Roughing cuts with a rose cutter and a large tracer are taken first, and light finishing cuts are made with a finer tracer and with flat drill-shaped cutters having semi-circular ends, which are accurately ground to shape on special machines. Adjustable arm rests are provided for the operator. The originals used are iron castings taken from plaster casts made by the artist. The copy, when removed from the machine, is finished by hand by the engraver.

209 Model of Copying Lathe 1892

Scale 1 : 5

This model represents a lathe for turning articles whose form is irregular and section not circular, such as wheel spokes or gun stocks. The model is shown shaping a table leg.

The machine has an ordinary bed carrying two double headstocks, so forming two lathes with parallel axes. The front lathe is driven by a stepped pulley in the usual way, and by an intermediate wheel drives the back lathe in the same direction and at the same speed. A saddle slides on the bed, and carries a slide upon which stand two stout swinging levers connected above by a tie rod. To the front lever is attached a turning tool, and to the back one a blunt finger. In the back lathe is fixed an iron pattern of the shape desired, and in the front lathe is the work to be turned. A wooden spring keeps the copying finger in contact with the pattern, and change wheels and a central guide screw are arranged to feed the saddle along, while a trigger gear is added which releases the feed nut when the saddle has gone far enough.

210 The Cameograph Carving Machine for Photo-Sculpture

This machine is one of a series, built for The Edmunds Cameograph Co, under patents of 1921 and 1923 taken out by H. M. Edmunds for the production of three dimensional figures from photographs.

The photographs are taken in a dark room, and the sitter is illuminated by a beam of light which has passed through a fine etched screen carrying a number of parallel lines. The two cameras are set to right and left-hand of the lantern so that the straight lines projected by the lantern, appear as contour lines on the photographic plates. The contour lines only are requisite for the later operations.

If the movements controlling the cutting tool in the machine are so arranged that lateral movement of the cross lines in a microscope, following the guide lines on the negative, can be translated into vertical changes in the position of the cutting tool, then the tool will reproduce the original subject to some selected scale.

The negatives are enlarged or diminished according to the size of carving desired, but the degree of relief obtained may be varied through a big range in the machining process itself.

The machine is in effect a vertical milling machine, with an automatic traverse and return, and a hand-feed controlled by the operator, who follows any given line on the plate through the microscope, by manipulating the hand feed ; and as the microscope and cutter work in a definite but variable ratio to each other, the act of following the line alters the contour followed by the cutter, this continuing right across the plate.

The same process is followed over every successive line, thus, in effect, turning the contour lines vertically through a 90° angle, and so reproducing the features of the sitter.

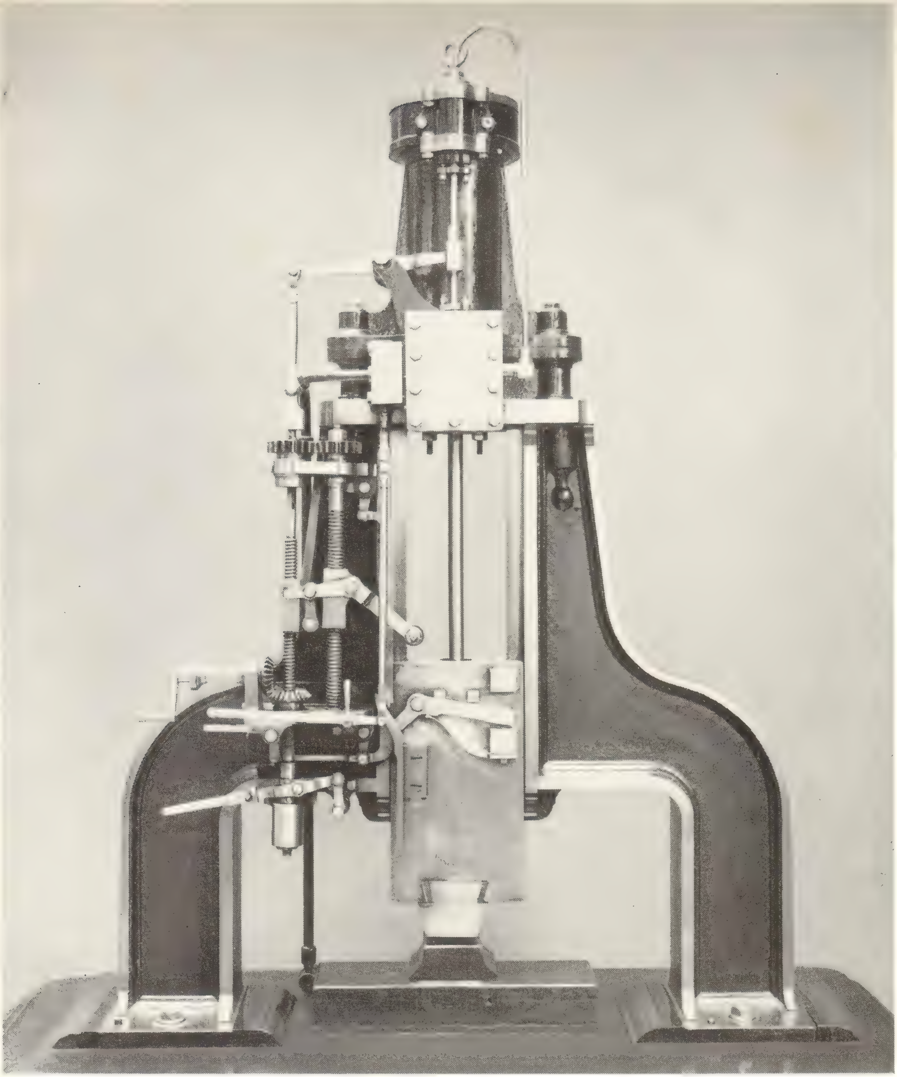
It will be realised that around certain features any given line may disappear from the view of one camera, but it is then visible to the other camera. As soon as the operator finds that a line has disappeared, he transfers his attention to the other microscope and carries on until it is again necessary to change.

Since the plates are right- and left-handed, the necessary correction in the right-hand microscope is in the reverse direction to that in the left. In order that the operator may not have to turn the feed the opposite way to attain apparently the same effect, so far as following the line is concerned, a reversing optical system is inserted in the right-hand microscope, whereby the mental process of following the line automatically is preserved. The feed lever on the left-hand side of the operator brings the reversing gear of the carriage into action, and at the same time advances the traverse to a pre-determined distance.

The degree of relief obtained from any given plate is varied by inserting different gear ratios in the cross shaft which engages with the vertical rack.

An over-running safety device is provided at the rear of the machine.

The machine will carve in many mediums, such as box-wood, ivory and alabaster, but the general method is to carve in a special plaster compound, the permanent plaques being cast therefrom in bronze.

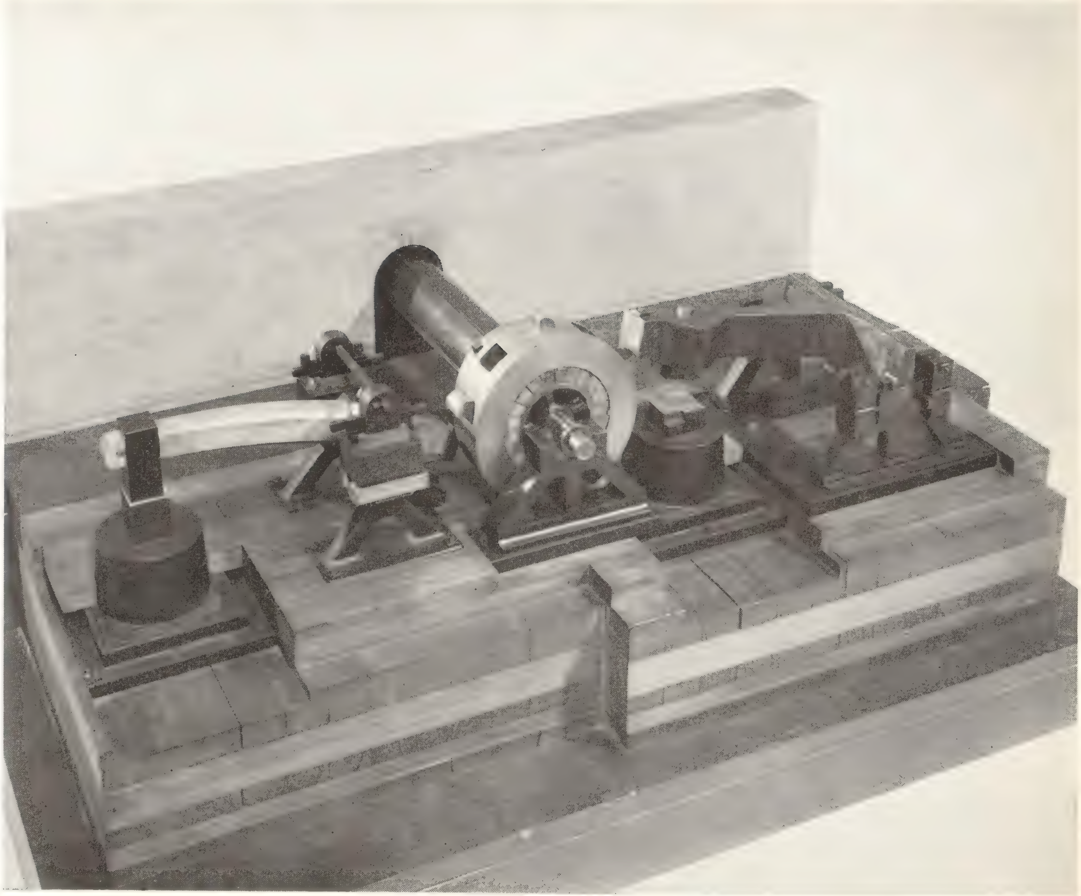


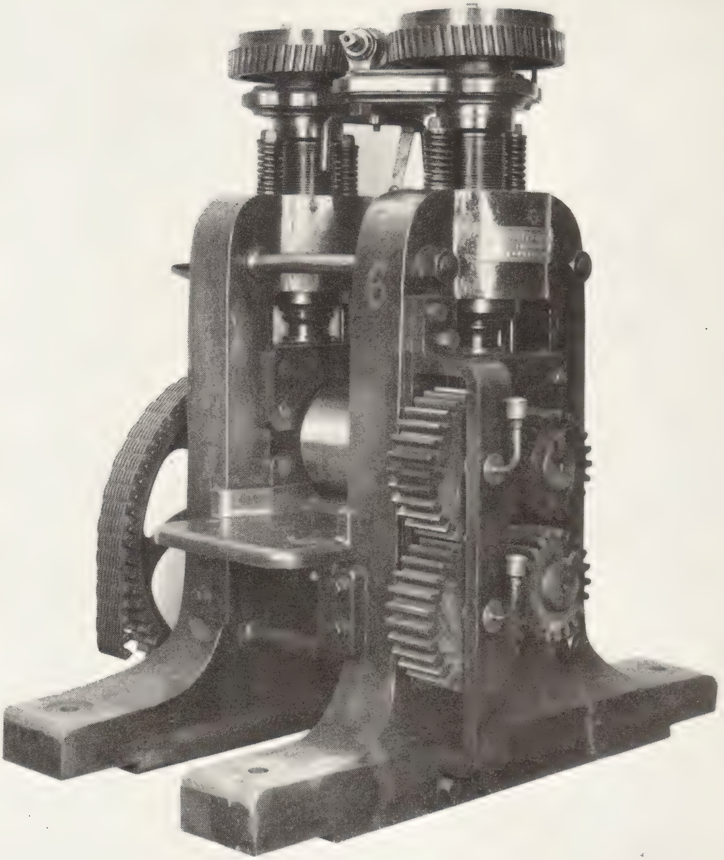
1 Nasmyth's steam hammer, (Model) (**9**)

G

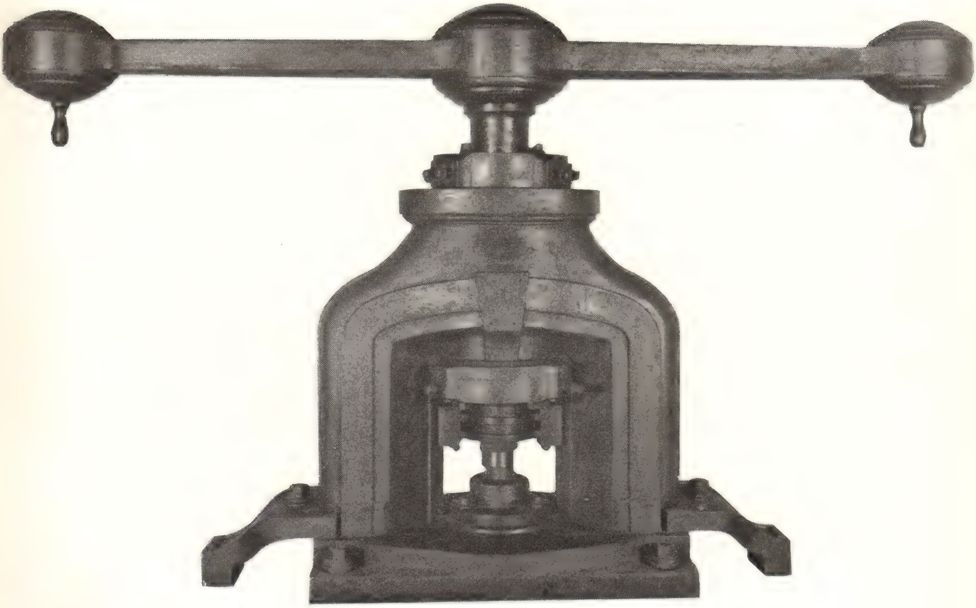
2 Hammer mill before the hammers were moved to the Museum (**5**)

3 Tilt hammer and lift hammer, 1804 (Model) (**8**)

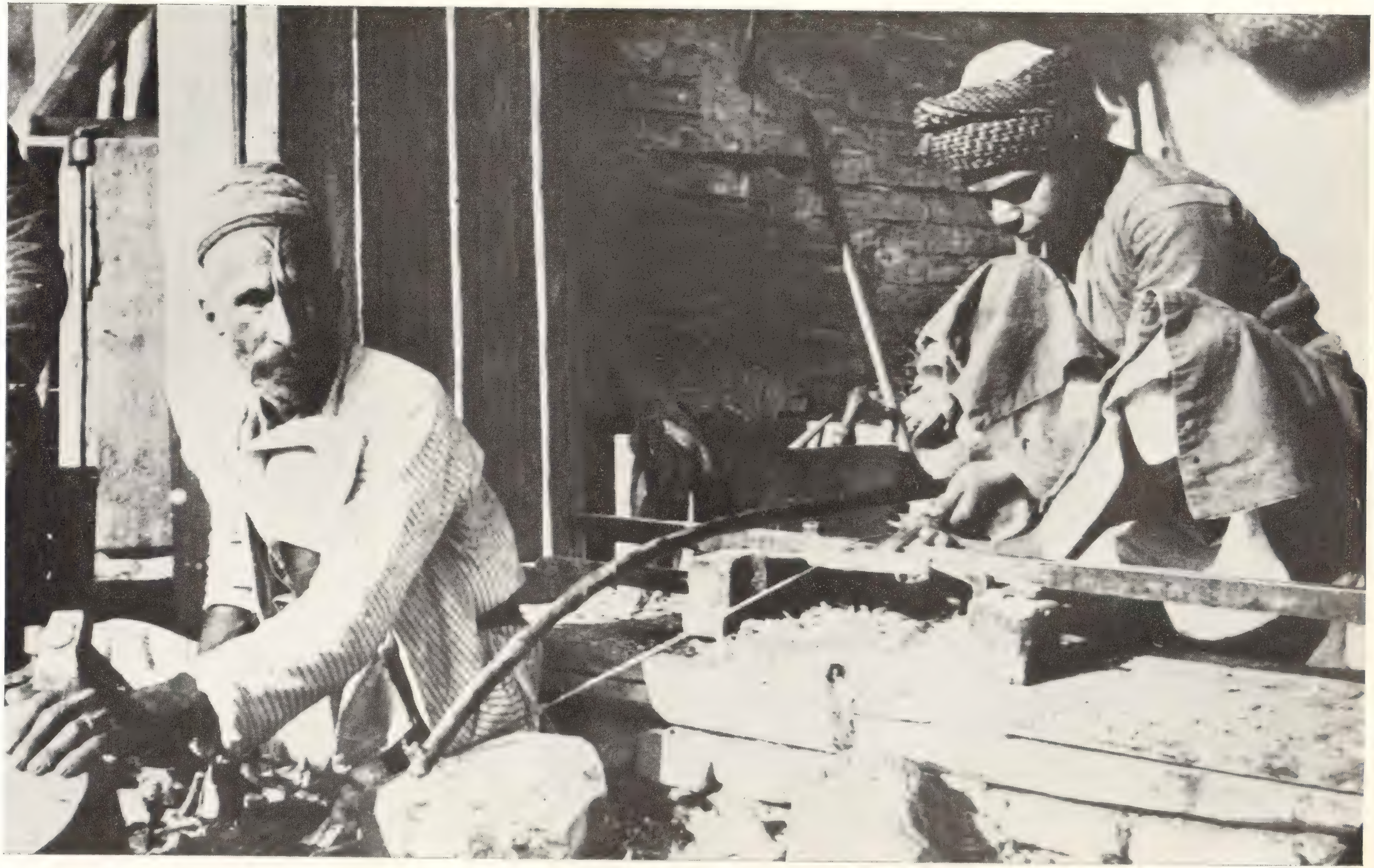




4 Rolling mill, 1882 (**21**)

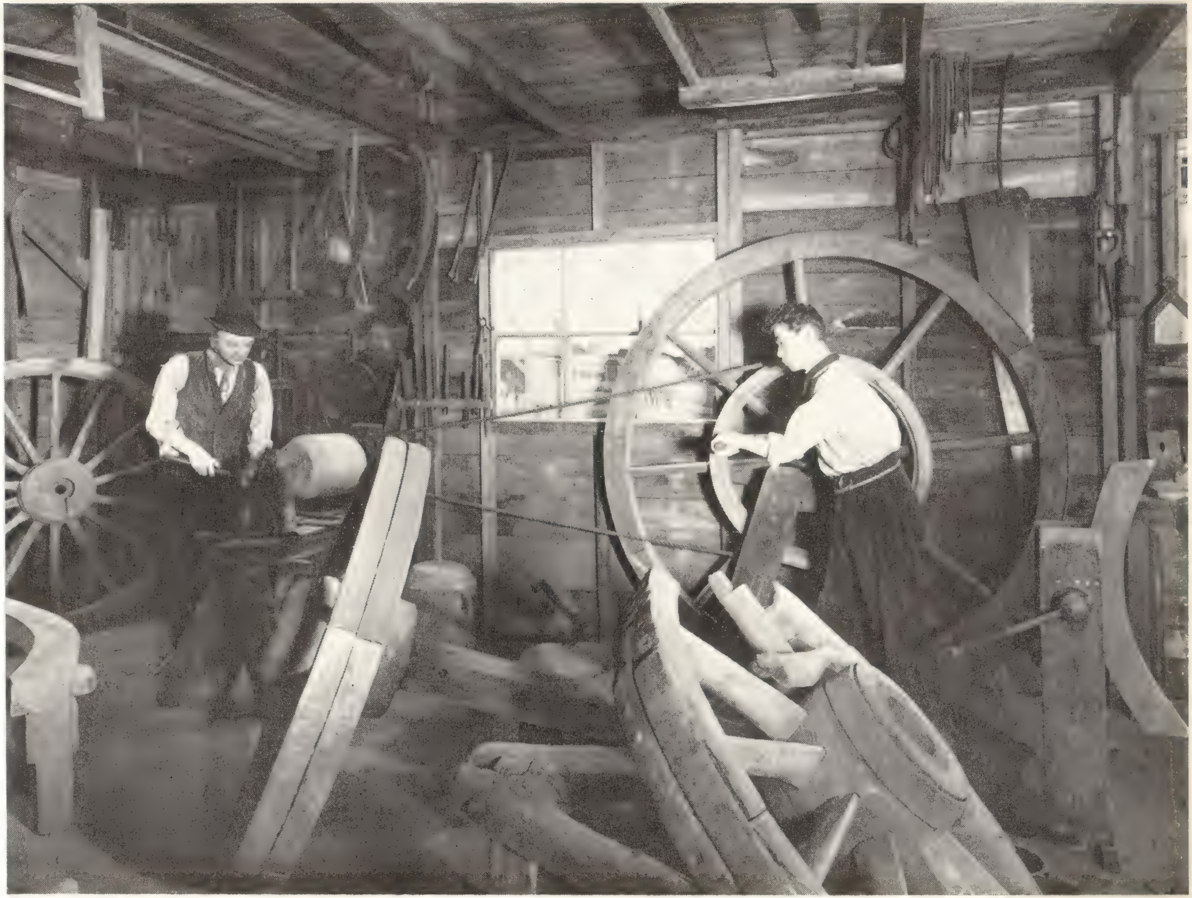


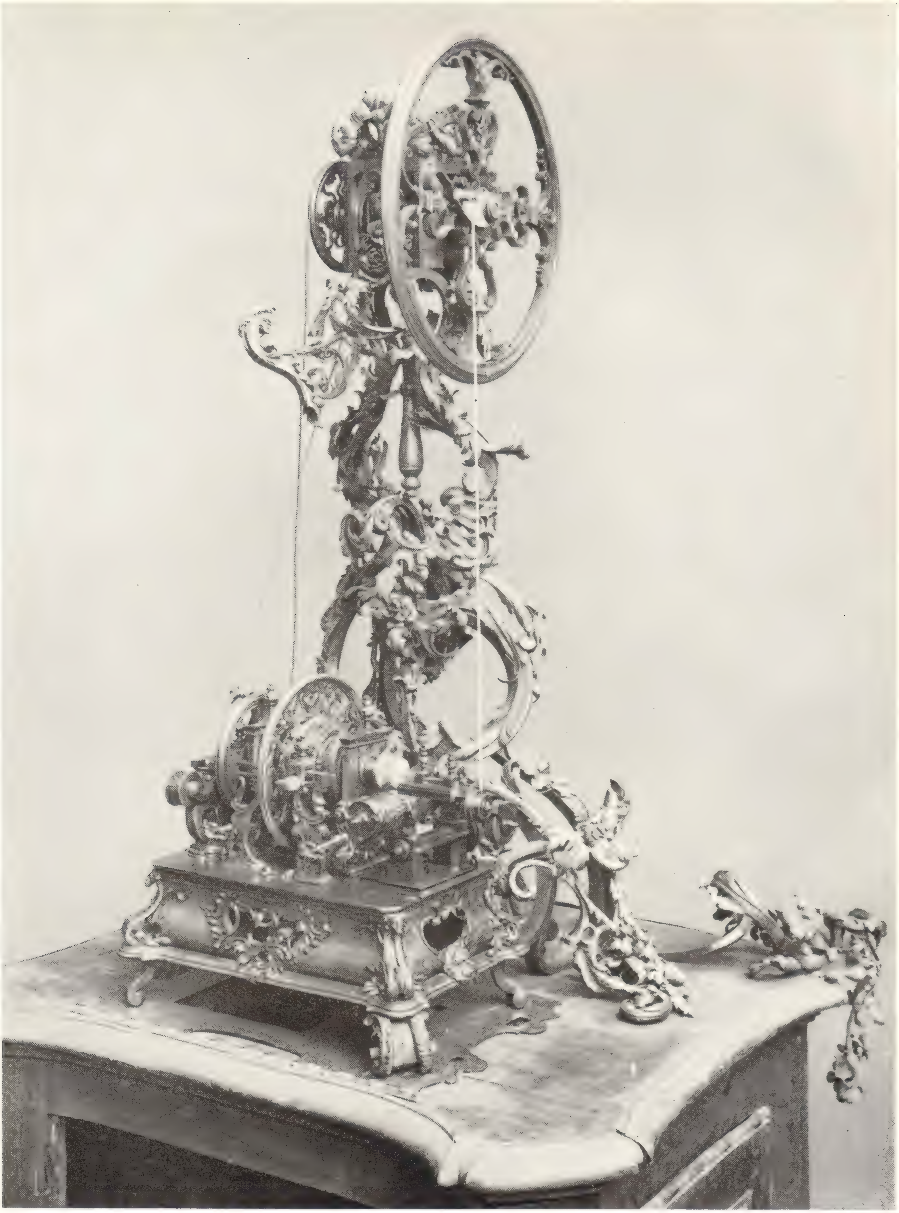
5 Medal press, 1862 (**37**)



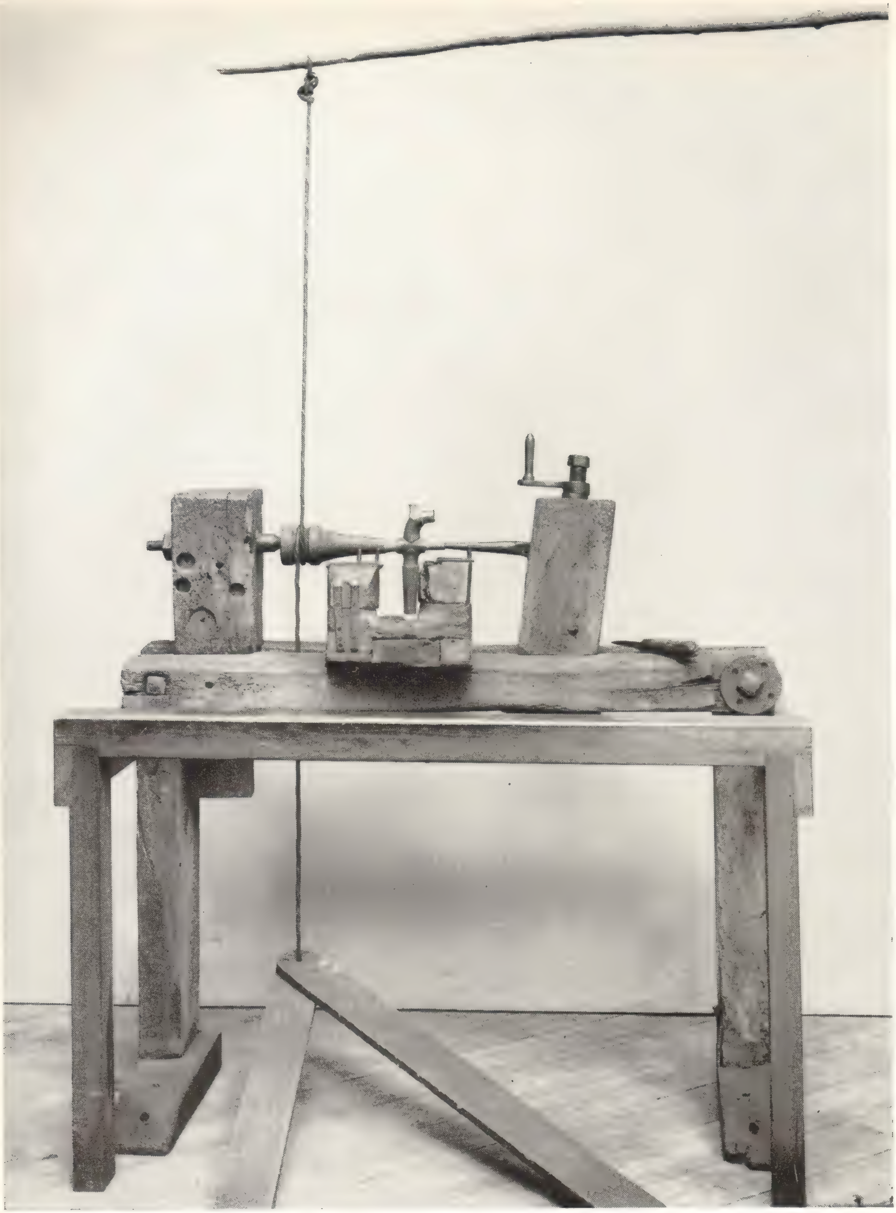
6 A bow lathe in use in a Baghdad workshop (**51**)

7 Great wheel lathe in the wheelwright's shop (**56**)



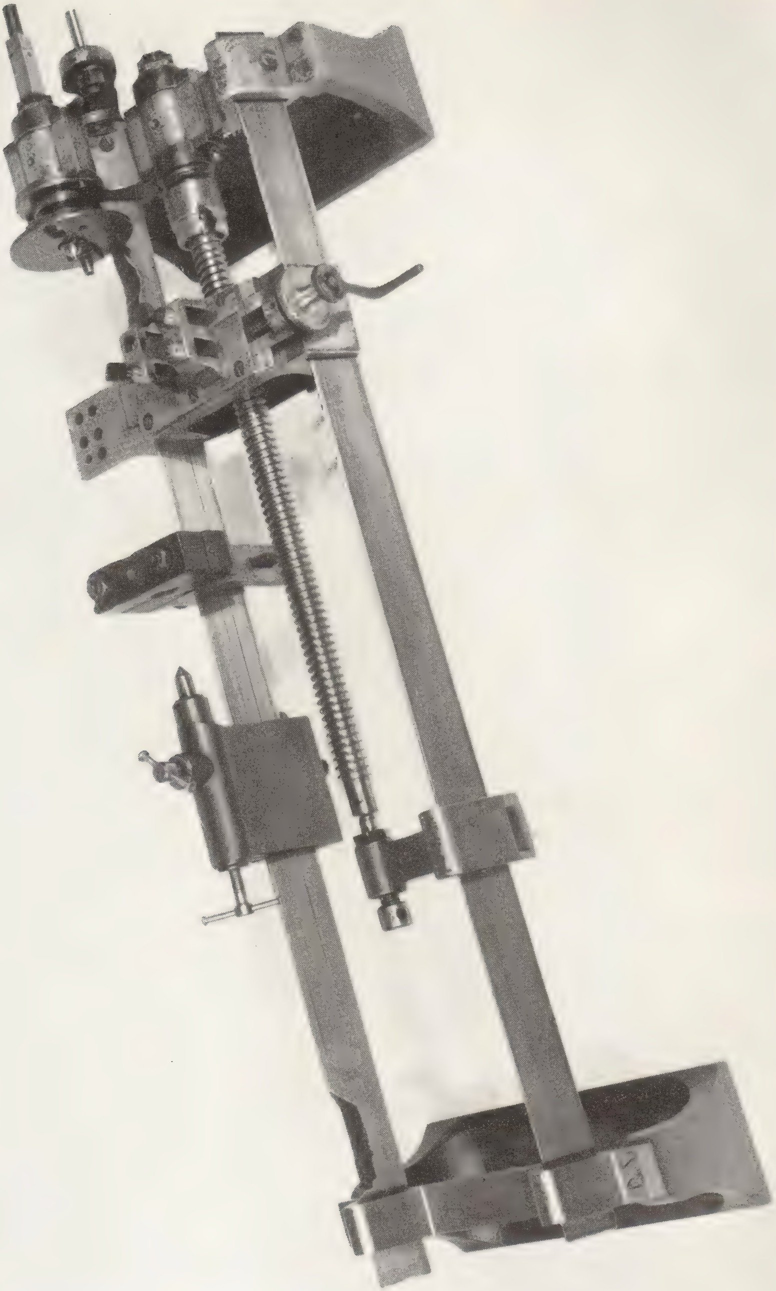


8 Rose engine lathe, c.1750 (**59**)



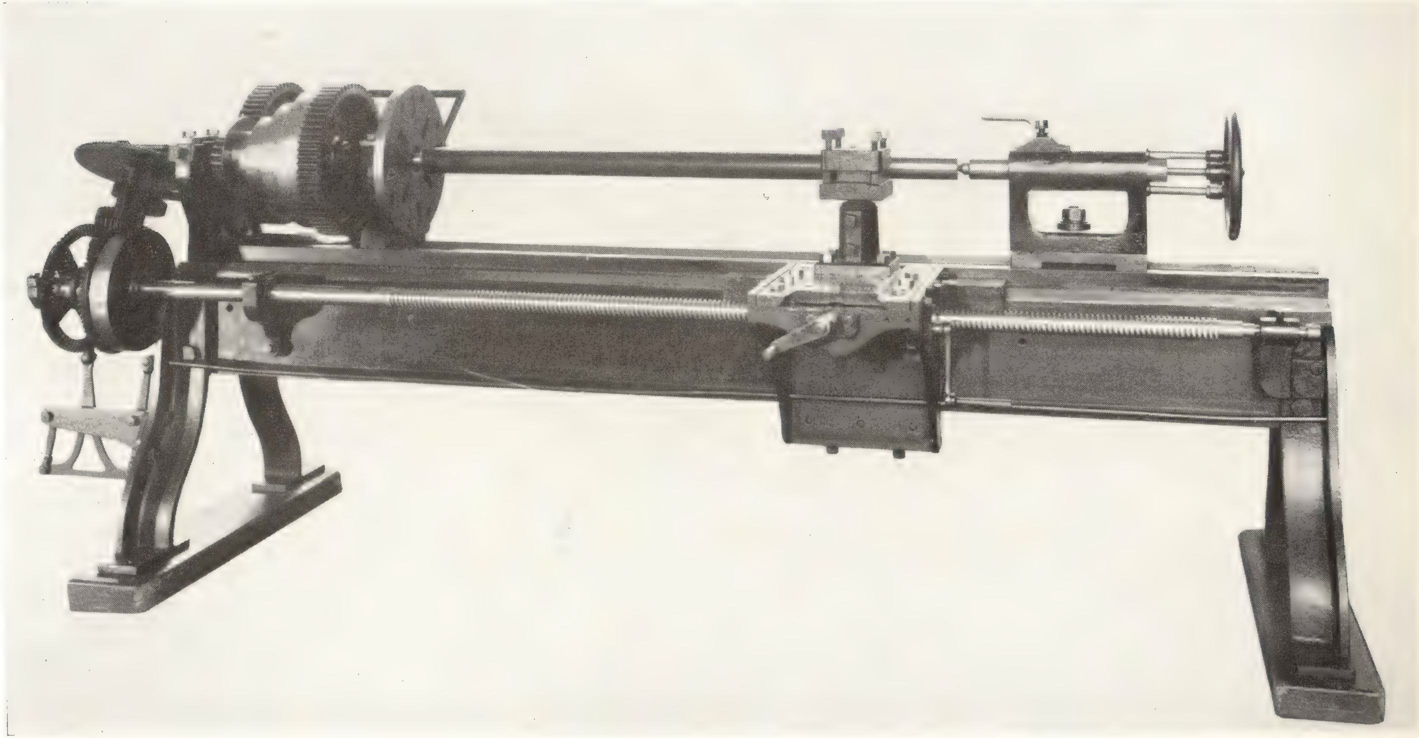
9 Pole lathe (**54**)

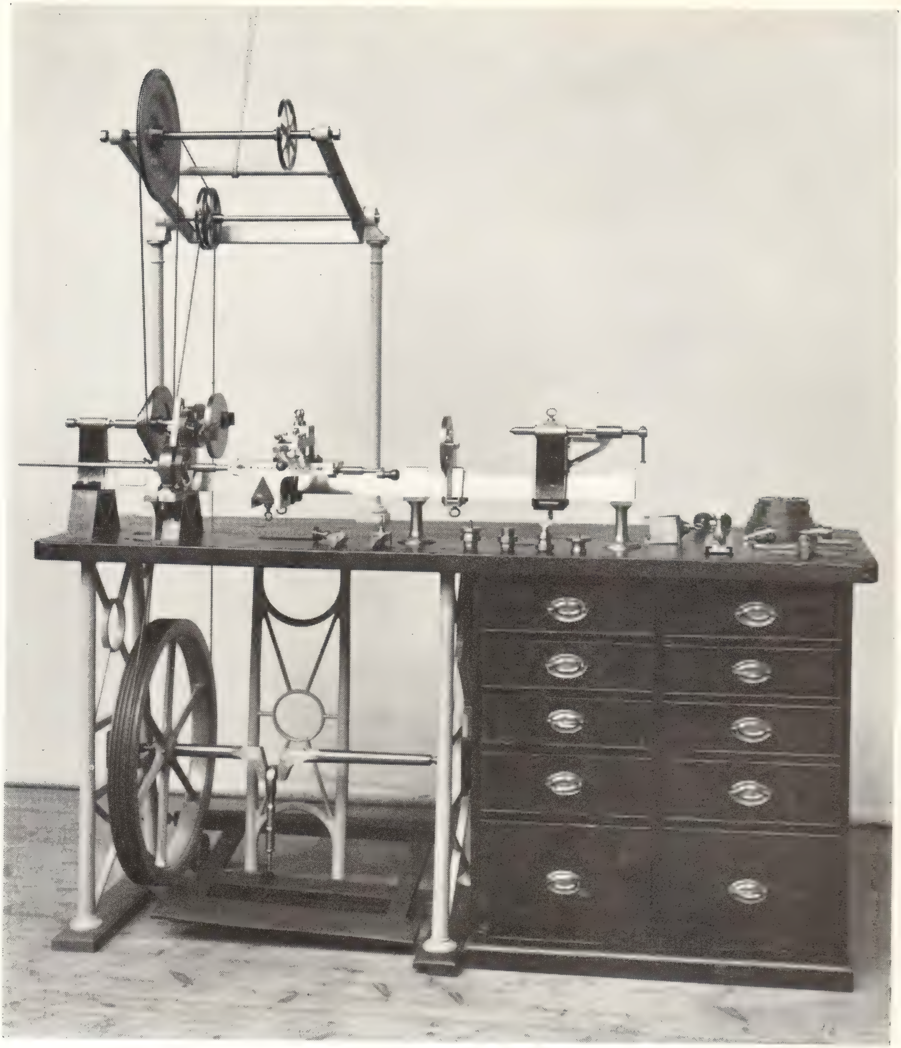
H



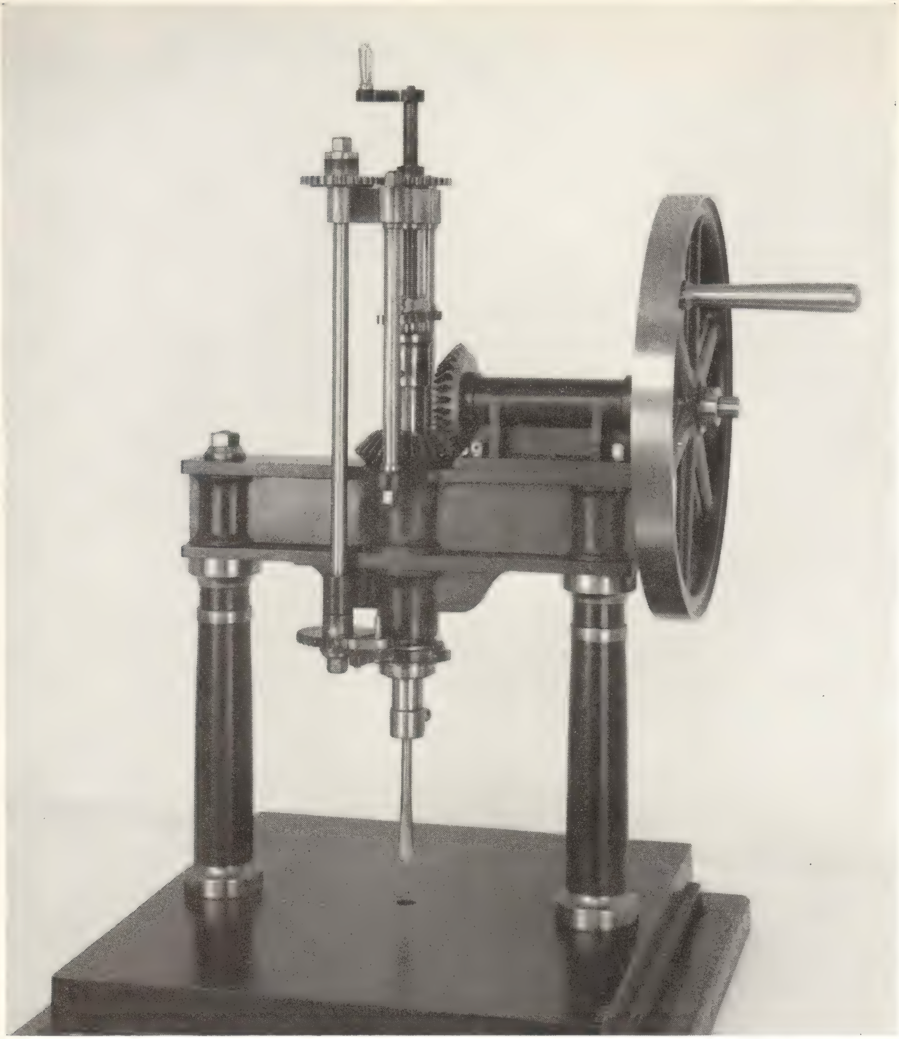
10 Maudslay's original screw-cutting lathe, c.1800 (**71**)

11 Roberts's back-geared lathe, 1817 (**74**)

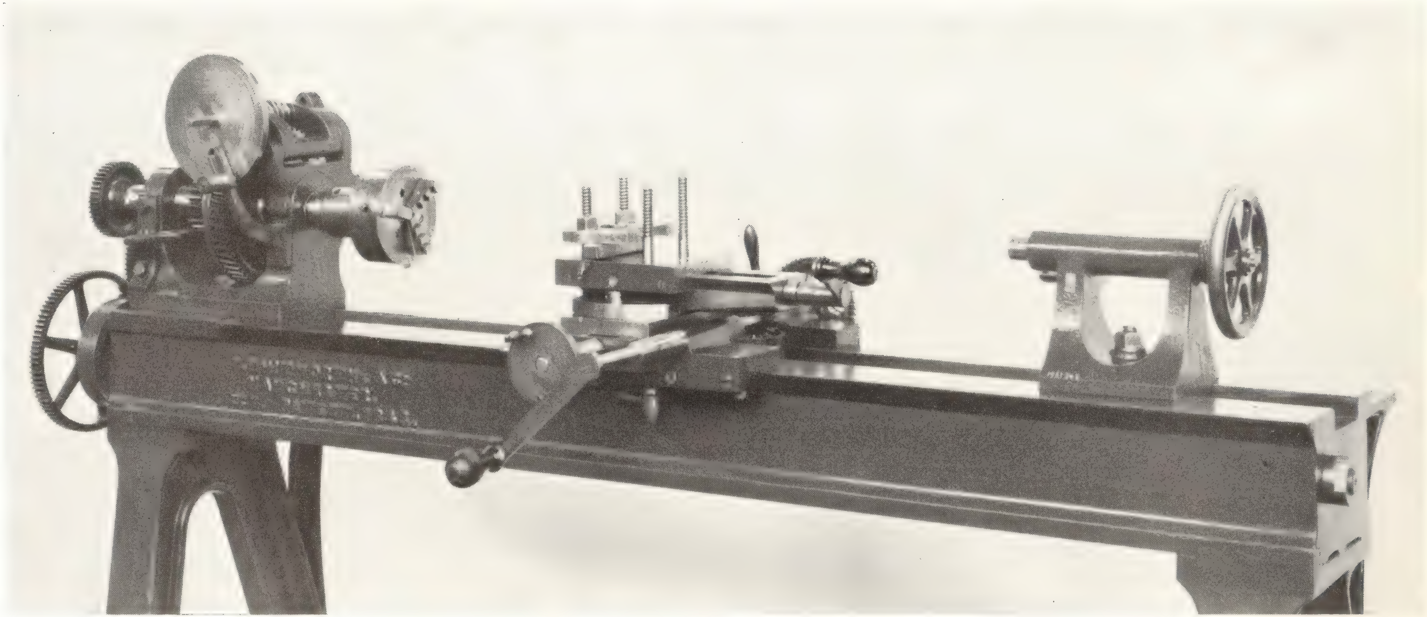




12 Bench lathe by Maudslay, c.1810 (**73**)

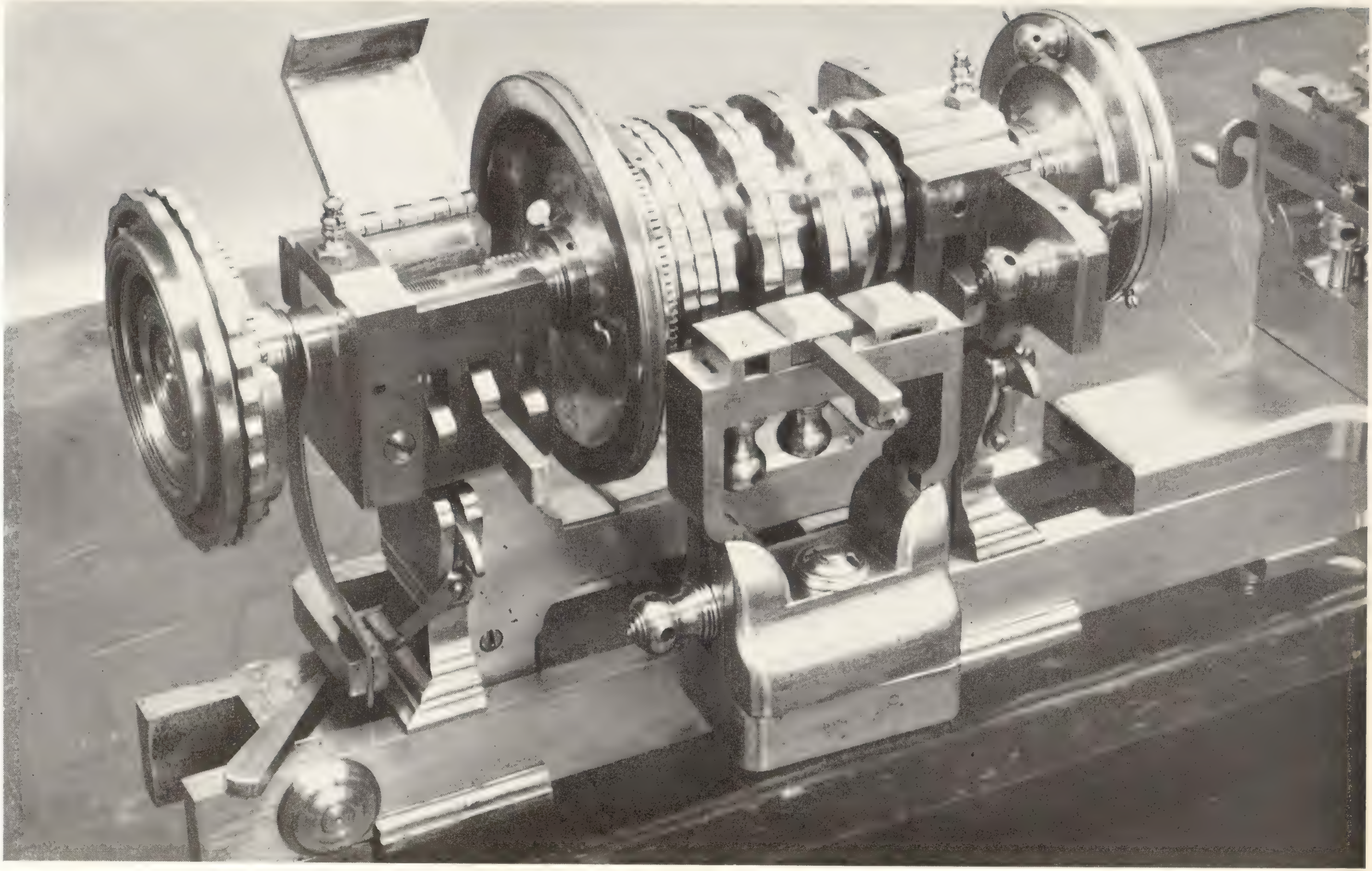


13 Nasmyth's drilling machine, c.1840 (**145**)

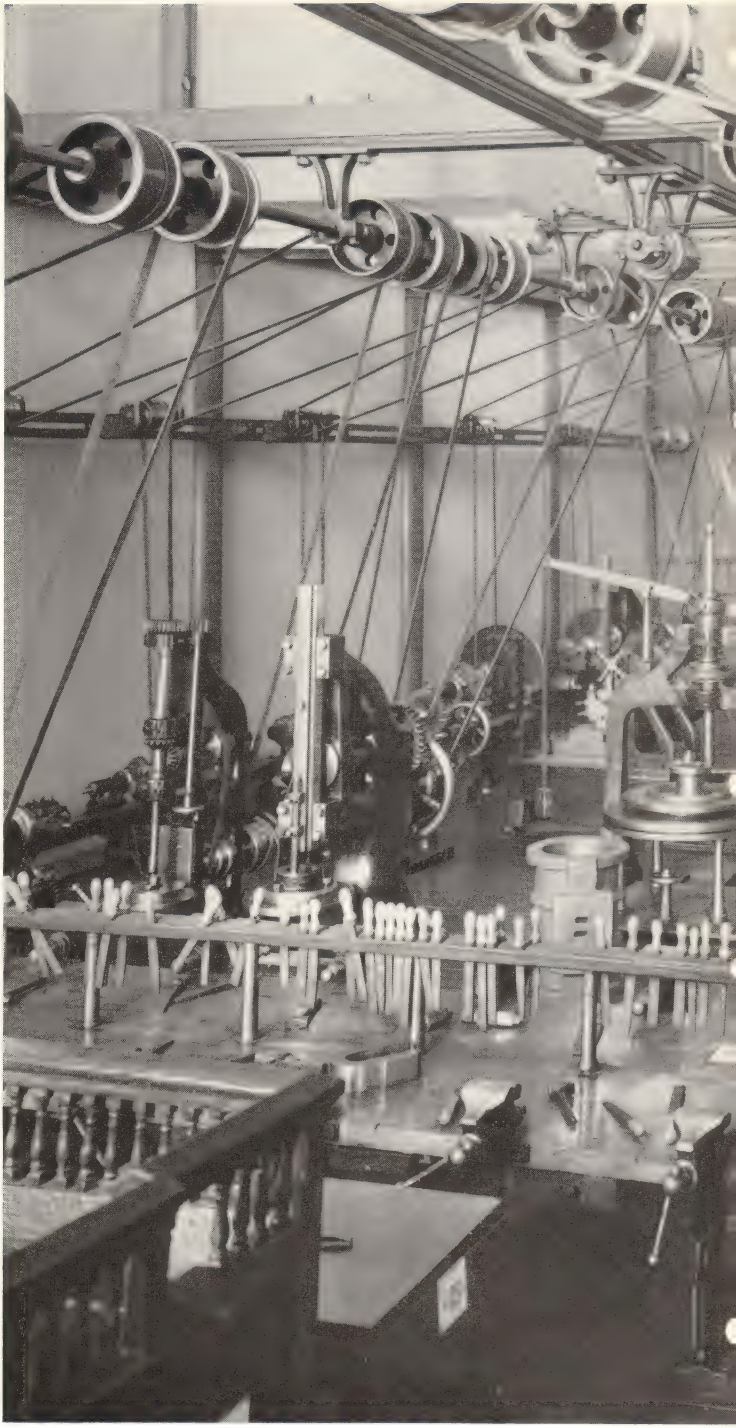


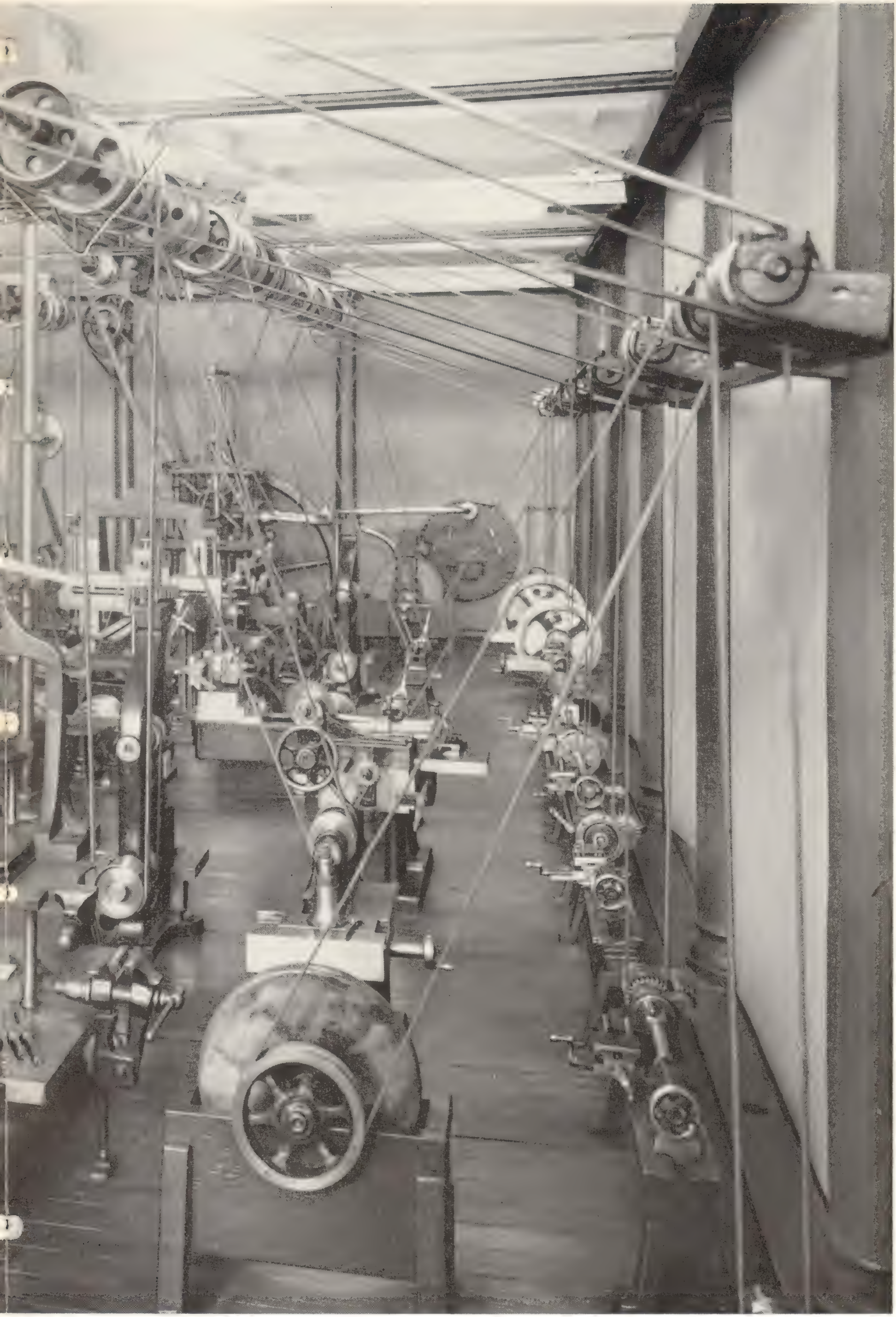
14 Self-acting lathe by
J. Whitworth and Co.
1843 (**78**)

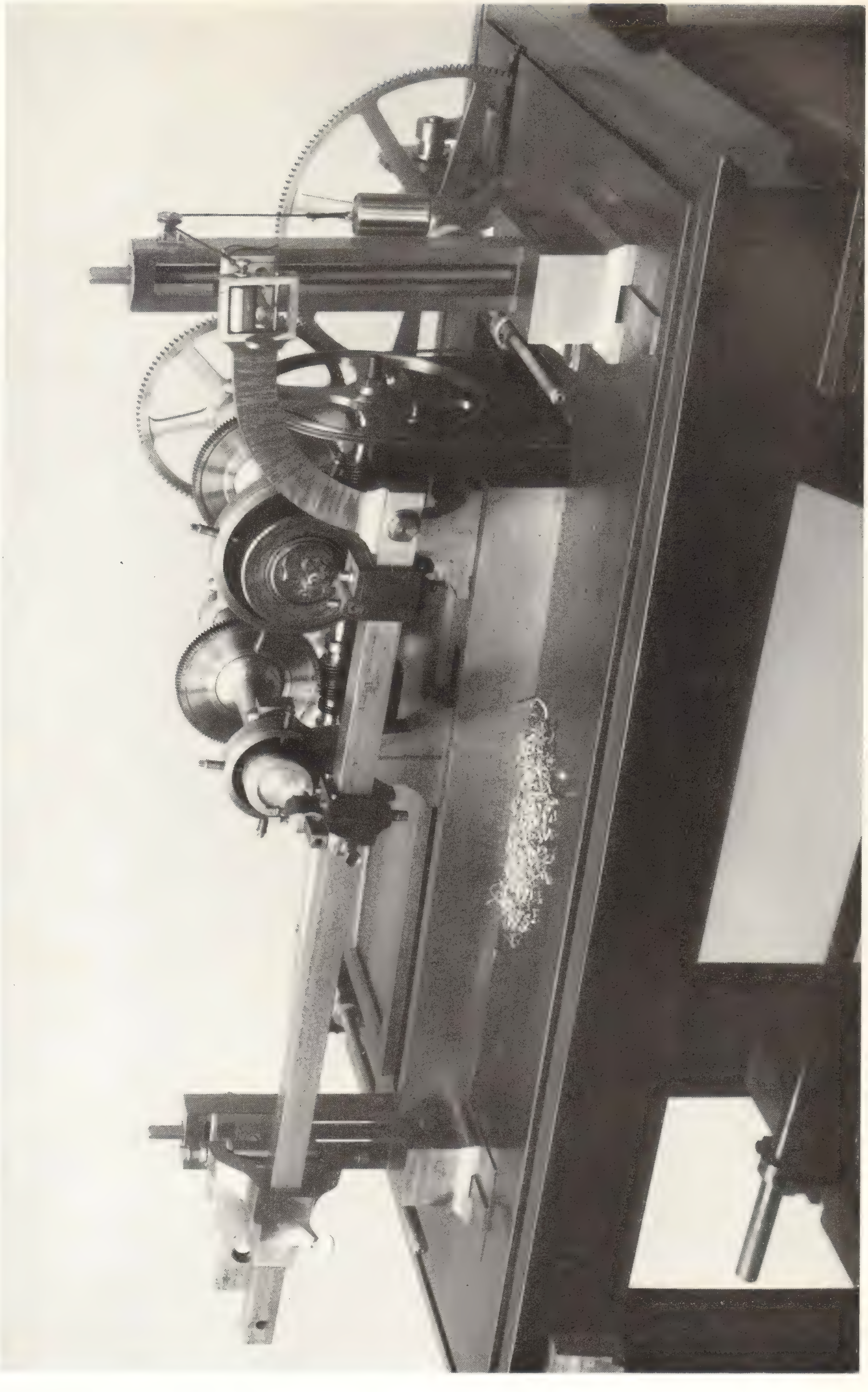
15 Headstock of ornamental
turning lathe, c.1740 (**58**)



16 Mid nineteenth century engineering workshop [contemporary model] (**239**)

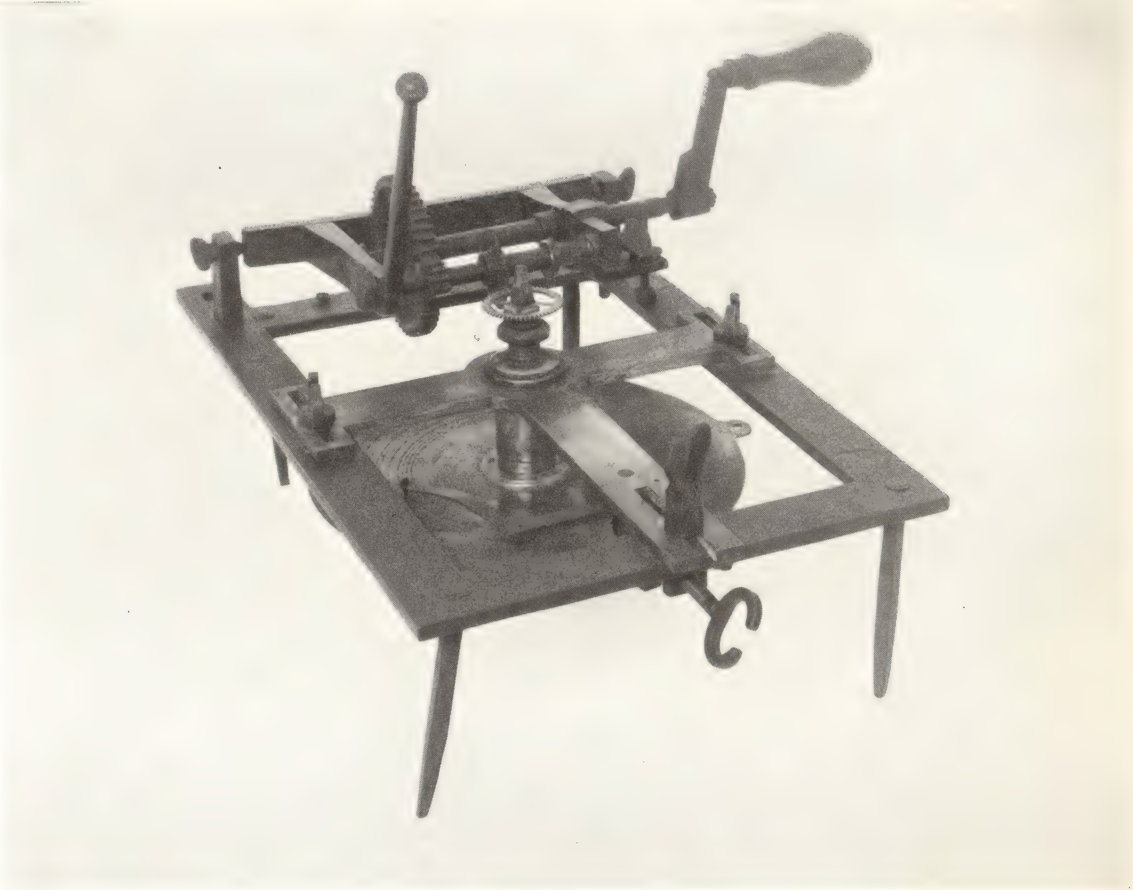


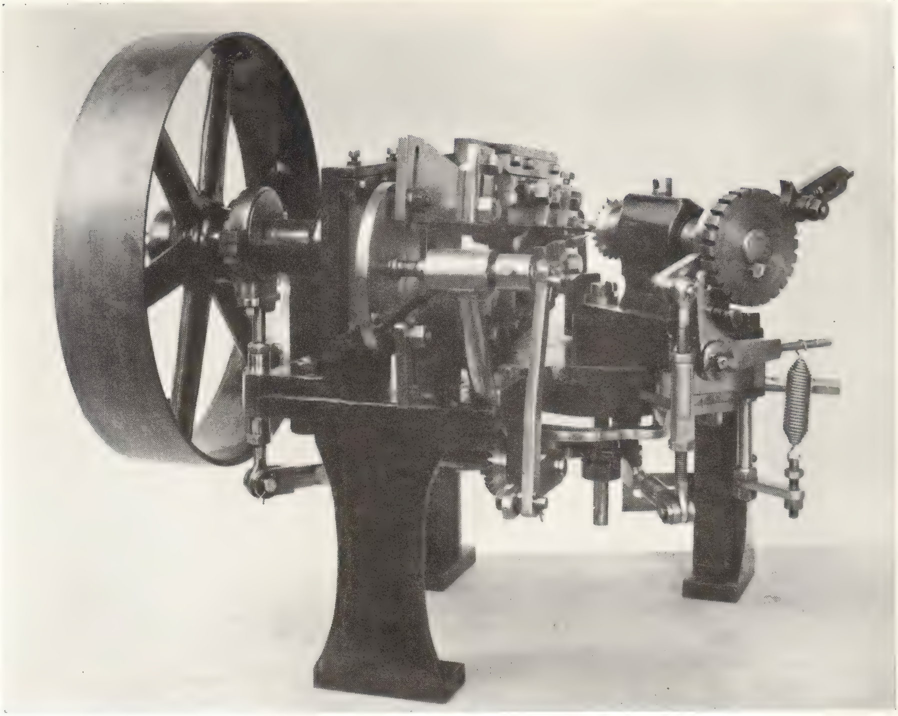




17 Engraving machine, early nineteenth century (**207**)

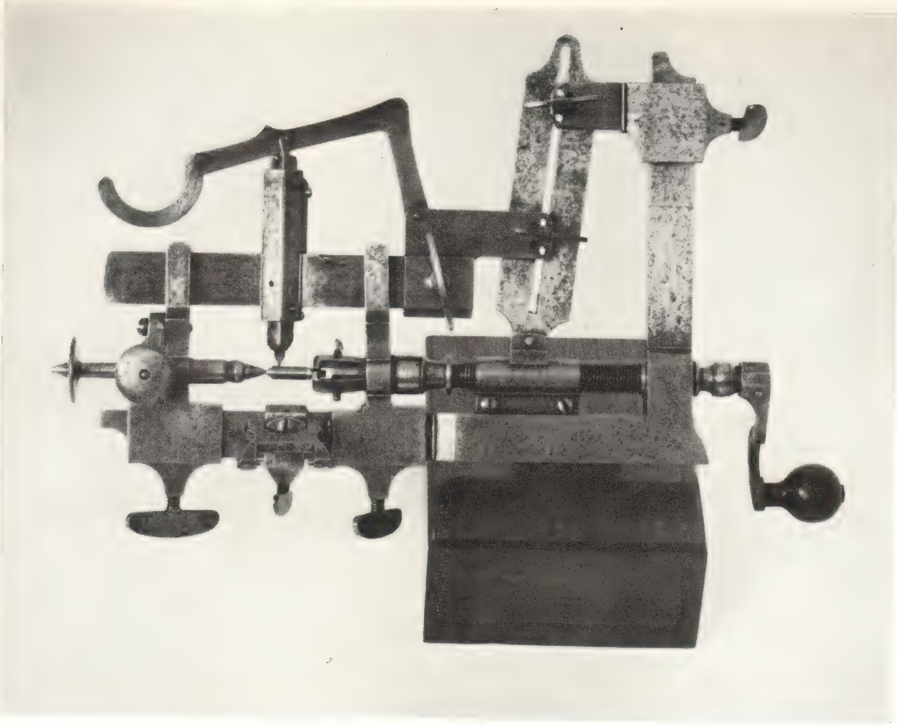
18 Clock-wheel cutting machine, seventeenth century (**170**)

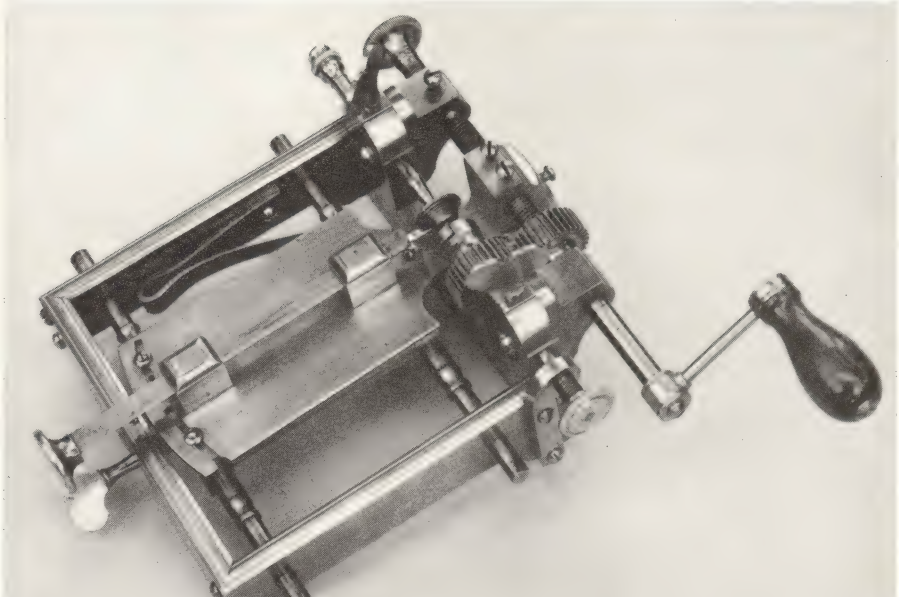


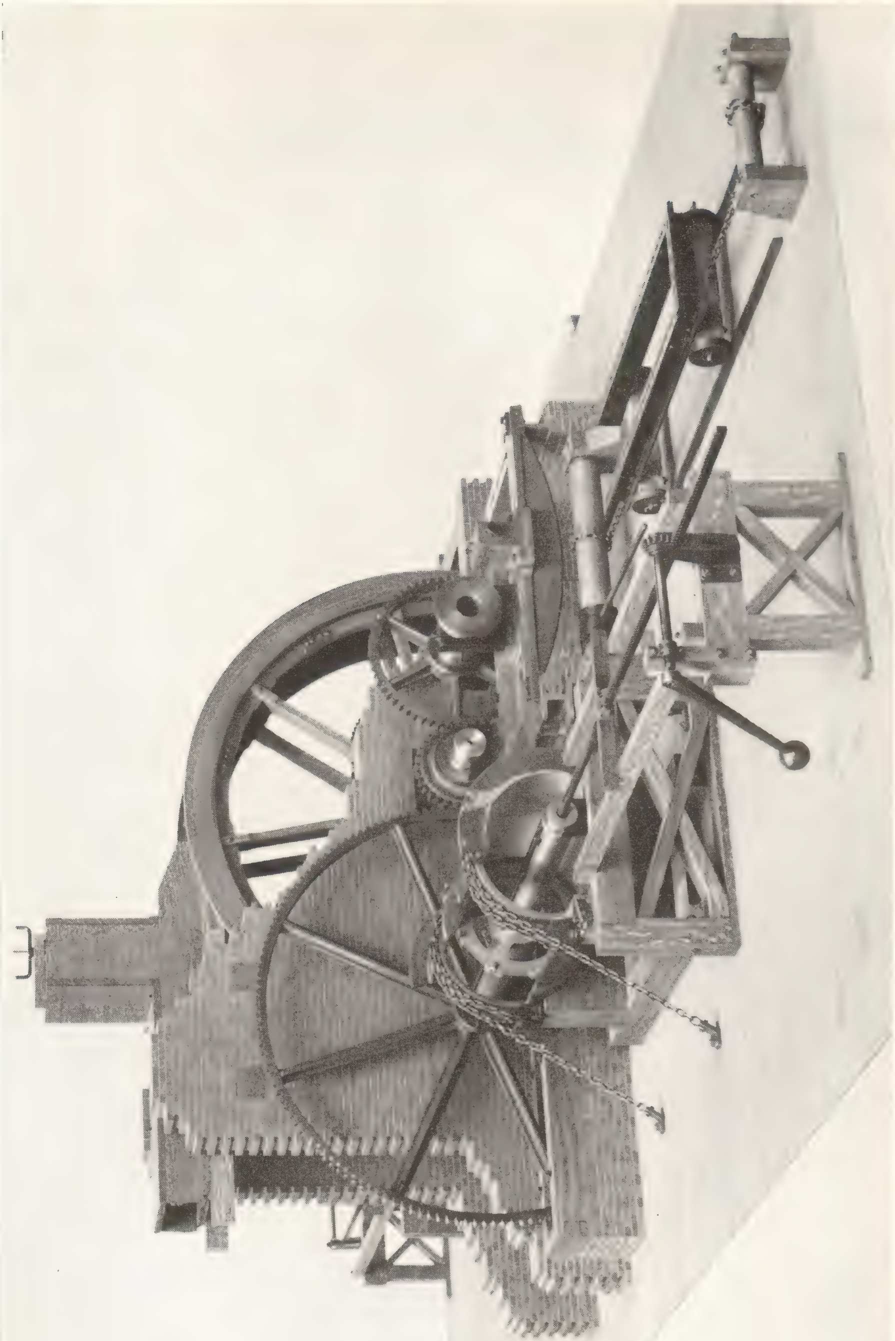


19 Original Robey-Smith bevel-gear shaping machine, 1895 (**180**)

20 and 21
Fusee engines, eighteenth century (**65** above; **63** below)

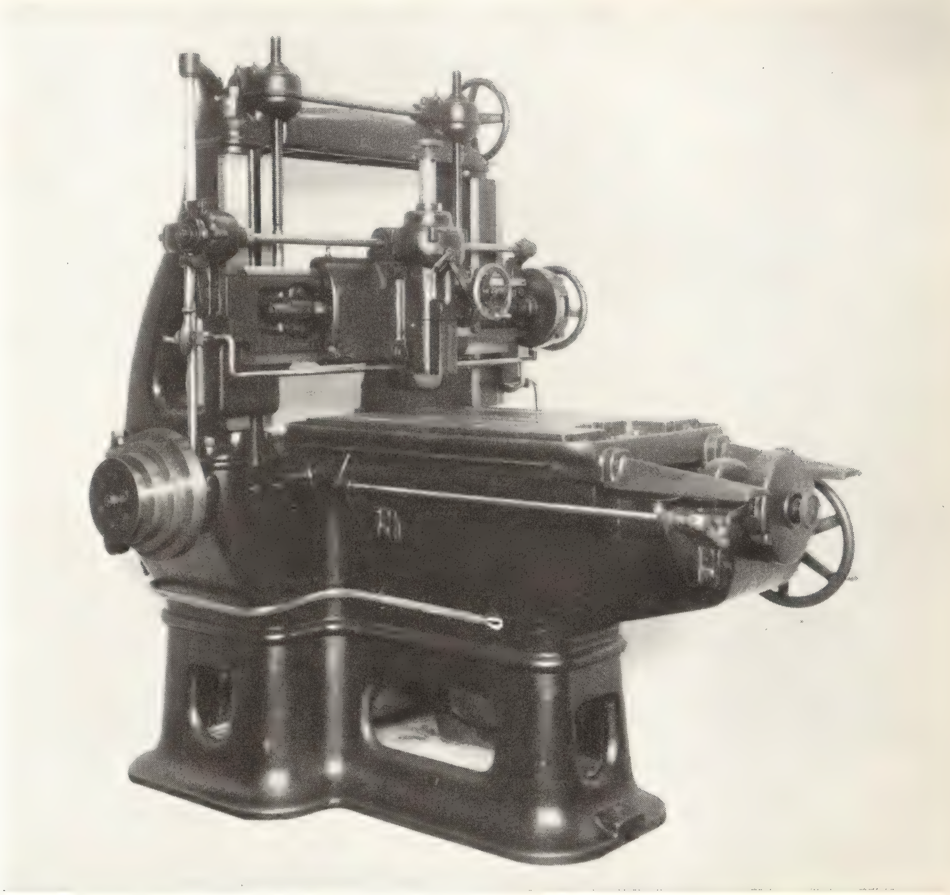




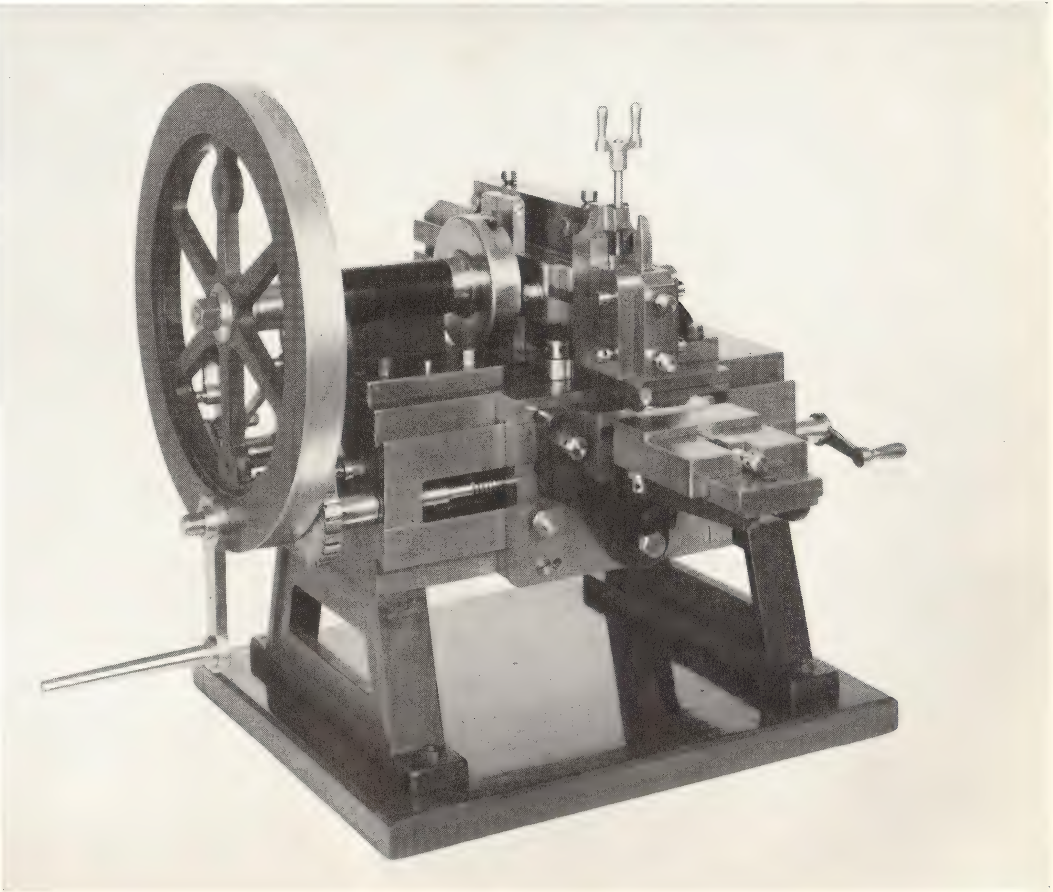


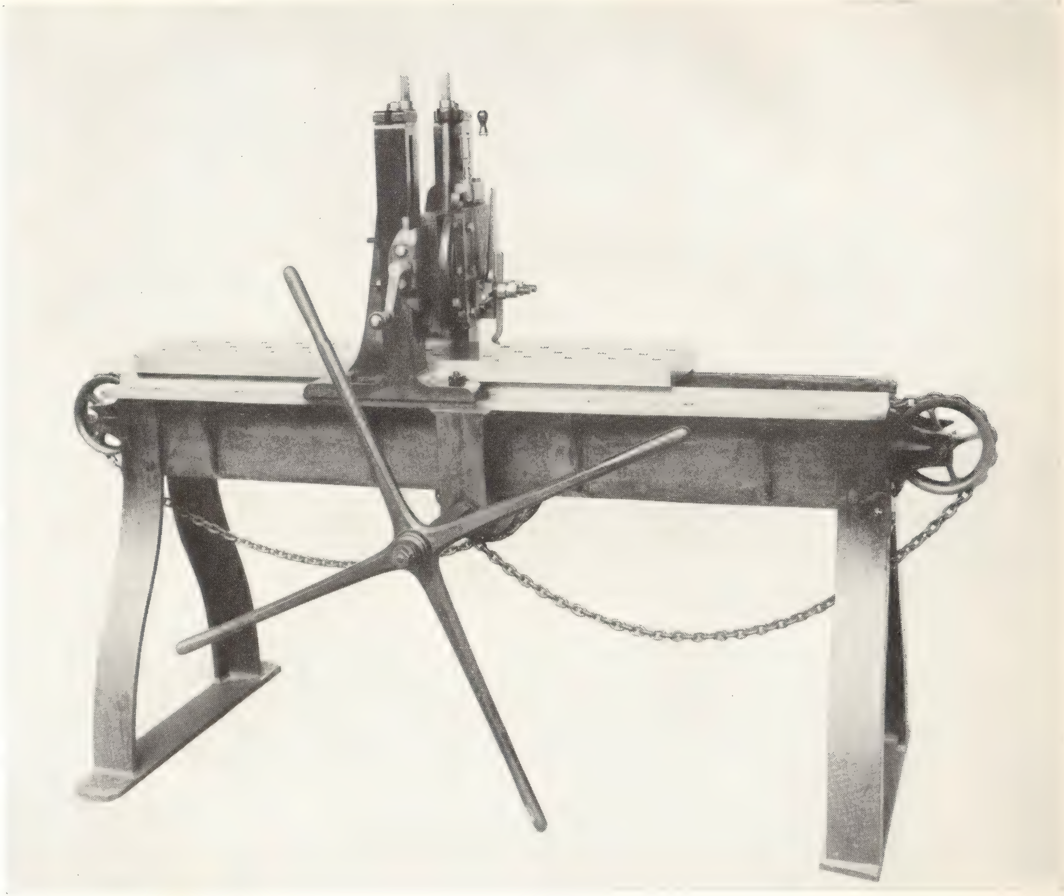
22 Wilkinson's cylinder boring machine at Bersham, 1775 [sectioned model] (**139**)

23 Jig-boring machine, 1921 (**151**)

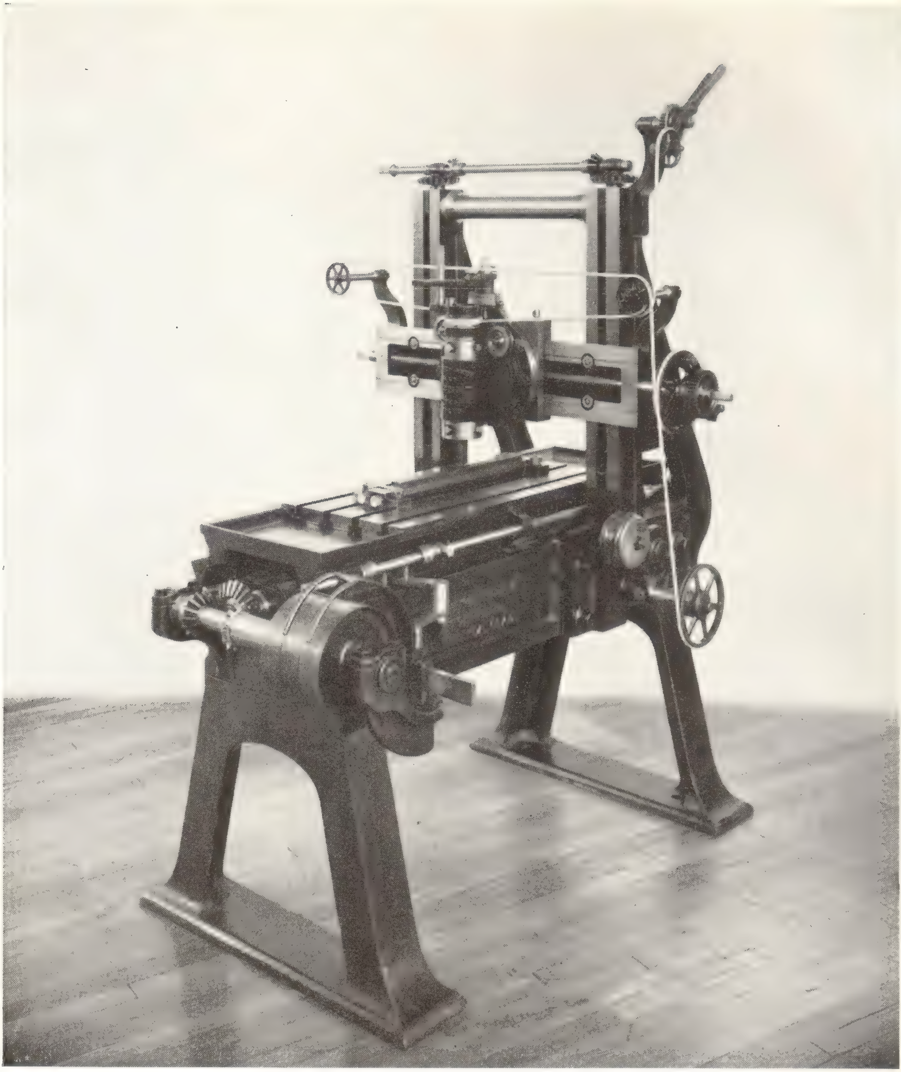


24 Nasmyth's shaping machine (**160**)

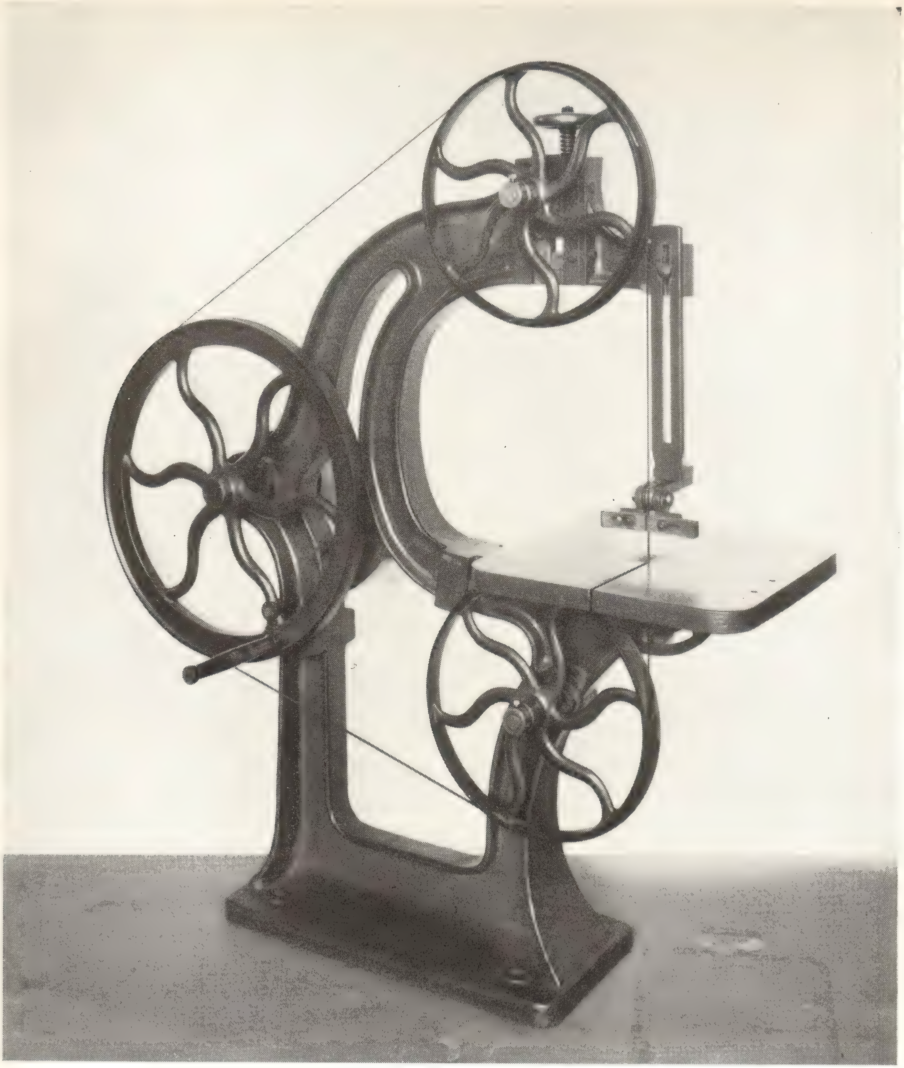




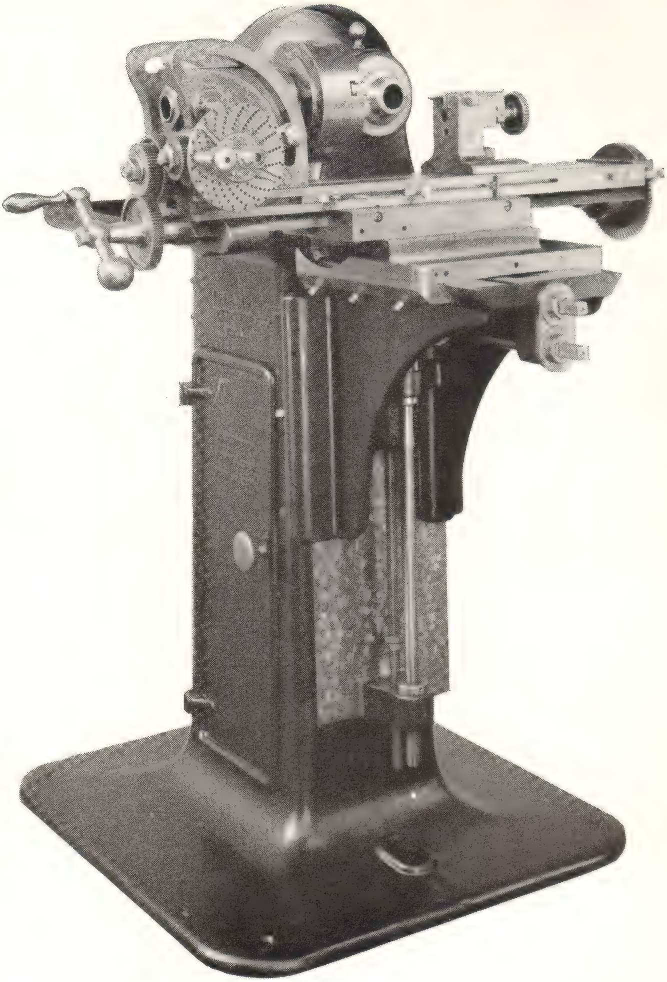
25 Roberts's planing machine, 1817 (**155**)



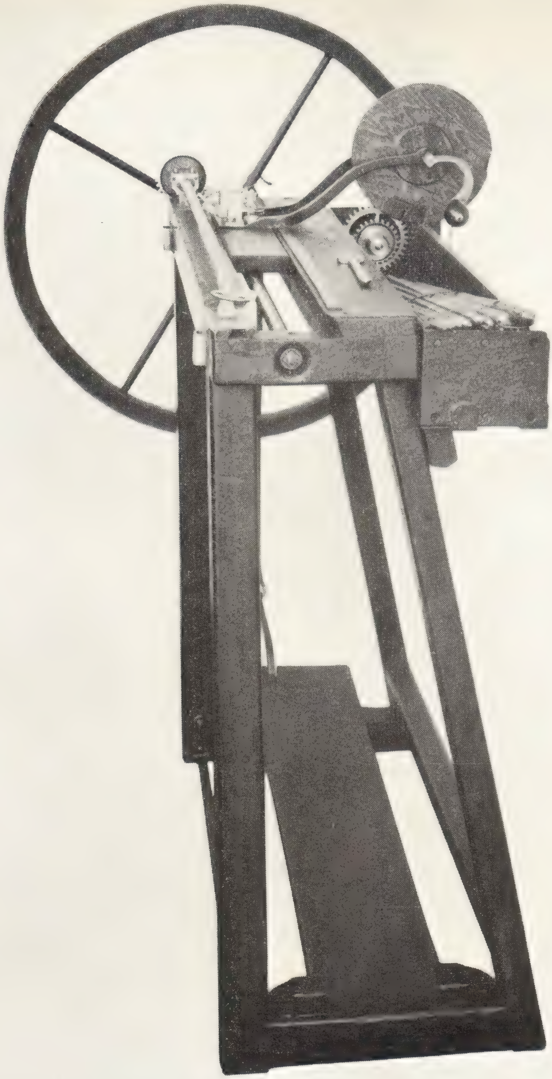
26 Planing machine by
J. Whitworth and Co.
1842 (**156**)



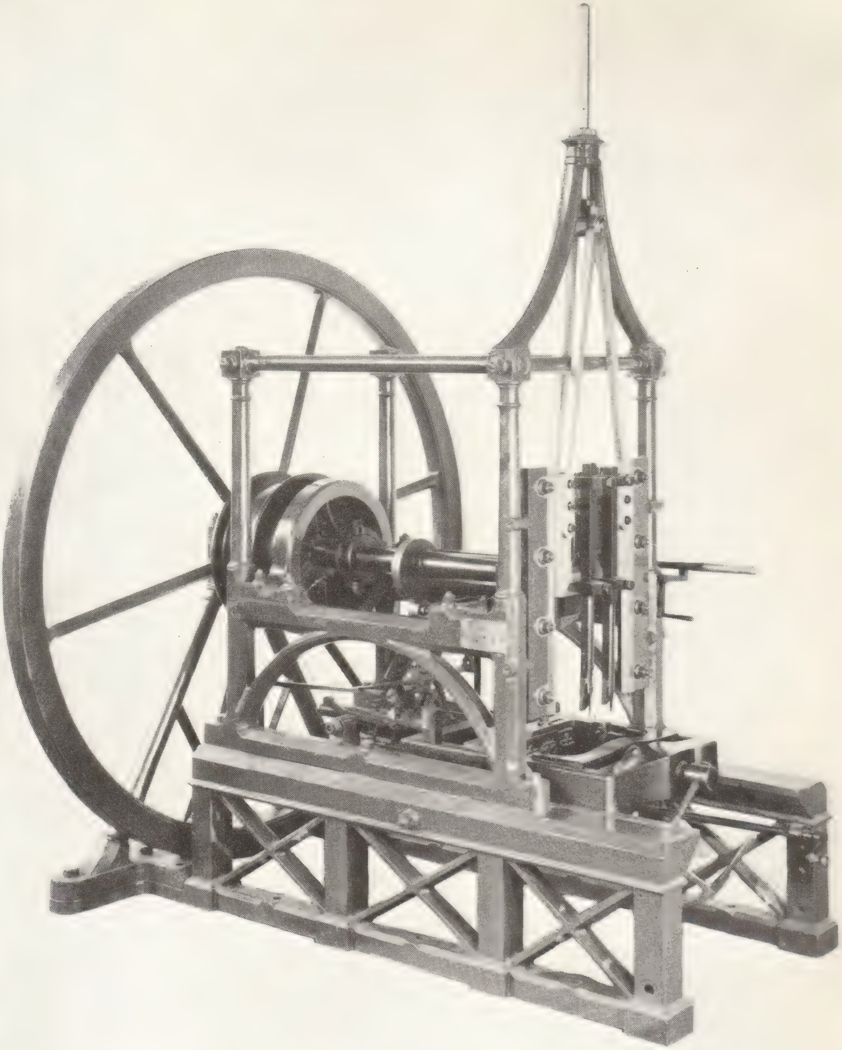
27 Band saw, 1888 (**195**)



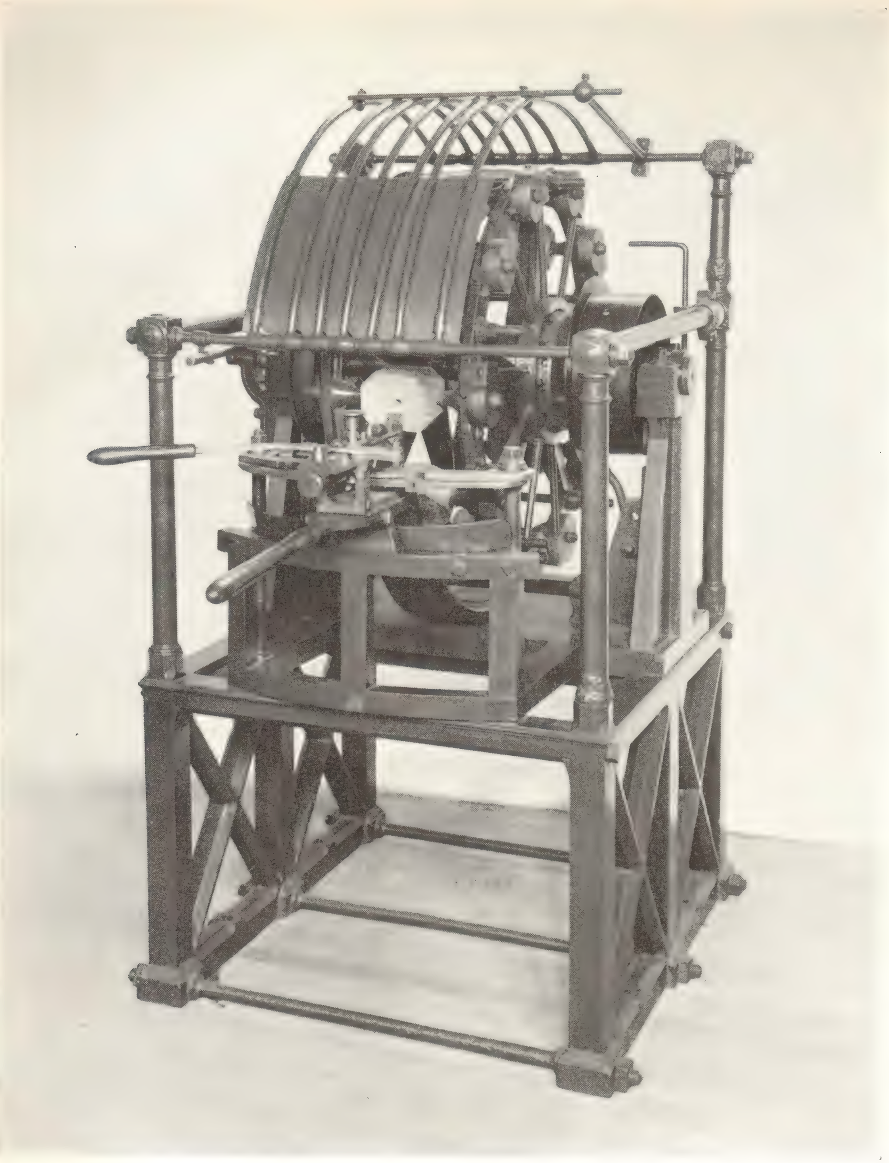
28 Universal milling machine, 1865 (**167**)



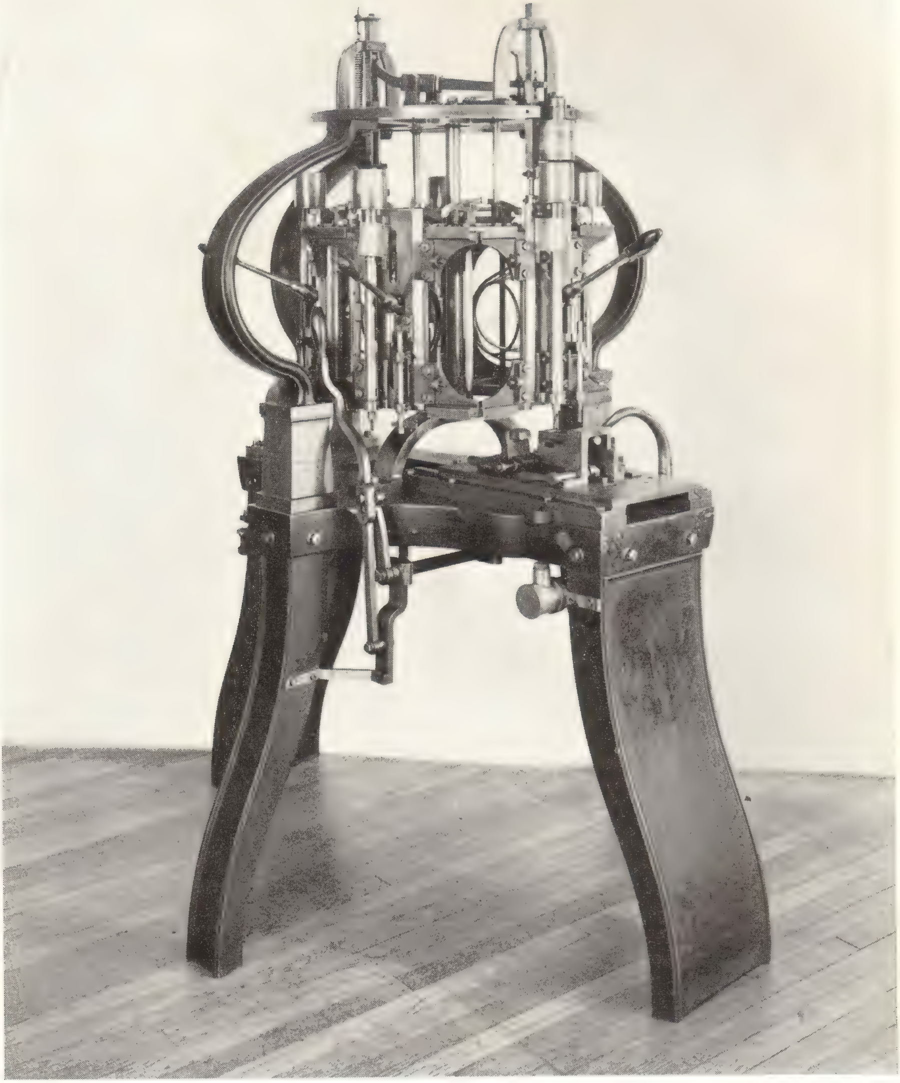
29 Bramah's spring winding machine, c.1790 (**214**)



30 Brunel's mortising machine, 1803 (**219**)



31 Brunel's block-shaping engine, 1804 (**220**)



32 Recessing machine,
1857 (**225**)

Special Manufacturing Machines

211 Quick Grip Vice c.1790

In 1784 Joseph Bramah patented a very successful lock, a partially dismantled example of which is exhibited (Inv. 1934-216. Photos 557/59, 558/59). The key depresses five pairs of spring-loaded steel strips which slide in slots in a brass barrel. The strips are also slotted and arranged to prevent the rotation of the barrel, and hence the bolt from moving, unless they are depressed to the correct positions.

The complicated mechanism could only be satisfactorily and economically manufactured by a well designed series of machine tools. To this end Bramah with the assistance of Henry Maudslay set up one of the earliest factories for precision metal working. From this plant there still survive the spring winding machine (**214**), the barrel sawing machine (**215**), some milling cutters (**212**), templates (**213**), and a quick-grip vice.

The vice is clamped in the gap in the bed of a lathe. It supports a cross slide with V's, one of which is adjustable for wear. On this is mounted the quick-grip device, which resembles a pair of tongs, the handles of which are closed and opened by a slide. In the vice were held the caps of the locks while the bolt run was slotted out by a milling cutter mounted on an arbor between the lathe centres.

212 Milling Cutters c.1790

These five milling cutters with one arbor for mounting between lathe centres were used by Joseph Bramah in the manufacture of the Bramah lock (see **211**). The cutters are forged steel cylinders, helically cut and finished by hand. They have the surface of a rough-cut file.

213 Templets c.1790

These six templets for drilling were used in the manufacture of the Bramah lock. (see **211**). Each templet consists of a steel disc with the appropriate holes, with a coaxial locating pin shaped to fit in the keyhole of the lock.

214 Spring Winding Machine c.1790

(*See plate 29*)

This machine was made in the works of Joseph Bramah for the purpose of winding the spiral springs needed for the barrel of the Bramah lock (see **211**). It is made on the lines of a screw-cutting lathe, driven by treadle and flywheel, and having a saddle which travels the entire length of the bed, and is drawn by a lead-screw.

The lead-screw is driven from a headstock by change gears which permit the relative speeds of headstock rotation and saddle travel to be varied. Instead of a cutting tool, however, the saddle carries a reel of wire which is wound onto an arbor held between centres. Maudslay's later work on screw cutting suggests that Maudslay, who was Bramah's foreman from 1789 to 1798, was responsible for the design of this machine.

215 Sawing Machine c.1790

This machine was made in the works of Joseph Bramah for the purpose of cutting slots in the barrel of the Bramah lock (see **211**). The saw is held in a frame that travels between adjustable V-slides and is reciprocated by a double-handed lever by man power. The barrel to be slotted is placed in the bush holder and this is then placed in the main holder indexed to cut 4, 5, 6, 7, 8, 10 or 12 slots in a barrel 1¼ in diameter and from 2 in to 8 in long. The holder is raised and lowered by a long lever at the side of the machine and the saw is guided and its thrust resisted by a lever bearing on the back of the saw.

216 The Portsmouth Block-making Machinery

This group of machines is of historic importance as representing the earliest large scale use of machine tools for mass production.

A scheme of manufacture to reduce the high cost of hand-made pulley blocks, of which the Royal Navy used 100,000 yearly, was proposed in 1802 by Marc Isambard Brunel and accepted by the Admiralty on the recommendation of Sir Samuel Bentham, Inspector General of Naval Works, himself an inventor of wood-working machinery. The machines were designed by Brunel and built by Henry Maudslay.

The machinery was installed in Portsmouth Dockyard and by 1805 was making all the blocks required by the Navy at an estimated saving of £17,000 per annum. It was claimed that 10 unskilled men could produce with the machinery as many blocks as had previously been made by 110 skilled men by hand.

There were 22 different kinds of machine and 45 machines altogether in order to make the blocks in the different size-ranges required. Eight of the more important and interesting of these machines are preserved in the Museum (**217-224**).

The first process in the manufacture of the shells was to saw elm logs into suitable lengths by means of the great pendulum saw or by means of a reciprocating saw. The lengths of wood were then squared on circular saw benches. A block thus prepared was bored by the boring machine with a hole for the sheave-pin and one or more holes at right angles to it to start the mortises. The holes were then elongated by the mortising machine to contain the sheaves. The outside surfaces of the shell were then formed by the shaping engine and grooves for the rope were cut by the scoring machine. The shell was finally trimmed and polished by hand.

The sheaves were cut from lignum vitae by means of the smaller circular saw exhibited or by a reciprocating saw. The slice of wood was then made circular and the centre pierced in the rounding machine. The seating for the bearing or coak was then cut by the coaking machine. The coaks were then rivetted and bored and finally the sheave was shaped on a lathe. There were other machines for turning and polishing the iron pins. Two thirty horse-power steam engines, one by Boulton and Watt and the other by Murray and Wood, were available to drive the machinery. A collection of shells, sheaves, and other components in different stages of manufacture is exhibited.

217 Pendulum Saw 1803

This saw is from the series of machine tools known as the 'Portsmouth Block-making Machinery' (see **216**).

This machine was employed to saw elm-logs into suitable lengths as the first stage in the manufacture of the shells.

The frame, consisting of two posts and a cross-piece, extends from floor to ceiling. A frame, supported on a fulcrum on the cross-piece and balanced approximately horizontally, carries a vertical frame mounted as a pendulum at the lower end of which is mounted the spindle which carries a circular saw. The saw is directed by two winches which turn pinions on the pairs of racks, which are attached to the pendant frame near its ends.

The operator uses the controls to bring the saw, as it cuts, from the far side of the elm log towards him and can thus cut through a log the diameter of which is not much less than that of the saw. A winch is provided for drawing the log along the saw bench. The bench has been reconstructed from contemporary drawings, but the rest of the machine, except perhaps for the saw itself, is substantially original.

218 Boring Machine 1803

This is one of the group of machine tools known as the 'Portsmouth Block-making Machinery' (see **216**).

This machine bores two holes at right angles to each other in a block of elm as a stage in the manufacture of the shels. The larger hole provides a start for the mortising machine and the smaller hole is for the sheave pin. The borers are mounted on slides and are fed into the work manually by levers. On depressing a locking lever it is possible to move the larger borer sideways to an adjustable stop when double blocks are being made. The height of the other borer is adjustable by rack and pinion.

219 Mortising Machine 1803

(*See plate 30*)

This is one of the group of machine tools known as the 'Portsmouth Block-making Machinery' (see **216**).

This machine chisels slots for the sheaves in two wooden blocks starting from the larger of the two holes drilled by the boring machine. It can also be used for making blocks with two sheaves. It was one of the first machines to be fitted with a cone clutch and brake. By its means the shaft may be disconnected from the flywheel and the machine quickly brought to rest when it is necessary to change the blocks. Rotation of the shaft imparts a reciprocating motion to the chisels, which carry projecting tongues to clear the chips from the mortises. The machine is capable of working at more than 400 cuts per minute.

The blocks are held in a carriage which can slide horizontally by the action of a lead-screw. A nut on the lead-screw is bolted to a ratchet wheel which is advanced by the movement of a toothed lever actuated by a cam on the main shaft. The blocks thus advance after each cut of the chisels.

When the carriage has moved a predetermined distance, a weighted lever, which it has been supporting, falls and lifts the toothed level from the ratchet wheel, thus finishing the cut.

220 Shaping Engine 1804

(*See plate 31*)

This is one of the group of machine tools known as the 'Portsmouth Block-making Machinery' (see **216**).

This machine shapes simultaneously ten drilled and mortised blocks, each of which is held between a single centre on one side and a two-point centre on the other in a drum consisting of two wheels mounted on the same axle and joined by five bolts.

As the drum revolves, the cutter is moved across by the lower hinged handle and inwards by a second handle. The radial movement is ultimately limited by a template which determines the shape of the block. Opposite sides are shaped in the same way, but the other sides are cut to a different shape by lowering the guide wheel so that it runs on another template.

Simultaneous indexing of all the blocks about their centres is effected through bevel and worm gearing mounted on radial shafts, which are actuated by a central crown wheel. A pin on the crown wheel is engaged by moving forward a lever attached to the frame. This prevents the crown wheel from turning; so that, if the drum is rotated, the two-point centres revolve. The operator therefore rotates the drum by hand through four revolutions with the crown wheel locked in order to index the blocks through 90°.

221 Scoring Machine 1804

This is one of the group of machine tools known as the 'Portsmouth Block-making Machinery' (see **216**).

This machine forms the score round the block for the reception of the rope by which it is suspended in the rigging of a ship. Two blocks, as they come from the shaping machine, are scored simultaneously by circular cutters driven by a belt round the pulley between them. Both the cutter spindle and the frame which carries the blocks are capable of rotation about axes and are guided by the handles so that the pulley guard is moved in contact with a wooden pattern, formed in such a way that the grooves are cut to the required shape.

The blocks are held in two vices which are fixed to a plate which on the release of a catch may be turned through half a revolution, so that the second quarters may be scored without removing the blocks. The cutters are circular brass wheels with steel cutters fixed in gaps diametrically opposite.

222 Circular Saw 1803

This saw is from the group of machine tools known as the 'Portsmouth Block-making Machinery' (see **216**).

This machine was used for cutting slices of lignum vitae as the first process in making the sheaves. The framing of the machine extended from floor to ceiling in the original building. The log of lignum vitae from a tree previously cut into two-foot lengths is placed in the universal chuck which is carried by a moveable frame. This frame can be raised by means of a screw which passes through a nut in its upper cross-bar. The lower end of the screw rests on a step in a fixed cross-bar extending between the columns, and is rotated by a hand-wheel, thus raising the chuck which is prevented from running back by a ratchet wheel. The chuck is moved between cuts by an amount which is determined by counting the clicks. The lower end of the chuck carries a square spindle, which passes through a square hole in a large cog-wheel below the base plate and then enters a hole in the ground. This cog-wheel meshes with a small pinion at the lower end of a long spindle, which can be turned by a handle. The operator can thus rotate the chuck as the saw is applied to the wood and so cut through a tree of diameter approaching that of the saw. The saw is carried in a frame which can be swung horizontally like a gate.

223 Rounding and Drilling Machine 1804

This is one of the group of machine tools known as the 'Portsmouth Block-making Machinery' (see **216**).

This machine turns the peripheries and bores the centres of slices of lignum vitae, as a step in the manufacture of the sheaves or pulleys. The flakes of wood are held in circular jaws over which a crown saw passes. At the same time the drill, the advancing mechanism of which is linked with that of the saw. passes through the centre.

224 Coaking Machine 1804

This is one of the group of machine tools known as the 'Portsmouth Block-making Machinery' (see **216**).

The coaking machine is a wood-milling machine used to produce recesses in the sheave to receive the three lugs of a bell-metal bush or 'coak'.

The sheave is held at its centre by an expanding collet in a chuck. The vertical spindle carries a milling cutter, adjustment of depth of cut being made by setting the height of the work table. When in use, the depth of cut is limited by stops. The circular work chuck is provided with automatic registration of the work in three positions at 120° by the rotation of the chuck by a handle. The work is fed into the cutter by swinging the whole table about a vertical axis. The sheave is removed by raising the cutter and swinging the table right out.

225 Recessing Machine 1857

(*See plate 32*)

This is one of the machine tools installed at the Royal Small Arms Factory, Enfield, for the interchangeable manufacture of the Enfield rifle, when in

1855 to 1857 the 'American System' was introduced on the recommendation of a committee sent in 1854 to the United States of America by the Honourable Board of Ordnance.

The purpose of this machine, which was made by the Ames Manufacturing Co, Chicopee, Mass , USA, was to cut out the recess in the rifle-stock to received the lock.

The cutters are carried each on a spindle, mounted on five separate slides in a circular frame rotatable about a vertical axis. Each cutter under the control of a handle may be moved vertically and tangentially to the frame, and is attached to a tracer. The gun-stock is carried on a sliding table capable of movement at right angles to the other two movements and is controlled by a second handle. The table also carries a 'former', which is a block of hardened steel with a recess of the required shape. By manipulating the two handles it was possible to trace out the shape of the recess and thus reproduce it in the gun-stock.

Five different cutters were required to complete the recess. While they were being brought forward in turn, the driving band was automatically transferred to a loose pulley. The five operations could be completed in less than one minute.

Air from a small fan at the rear of the machine was directed through two tubes on to the stock and former in order to blow away the chips of wood.

226 Machine for Cutting and Pointing Pins, mid nineteenth century

In this machine built by W. Lusty of Dursley, wire is cut into lengths and then pointed by successive contact with three rotary files of decreasing roughness. In their passage through the machine the wire lengths are held by a flexible steel band in grooves cut in the periphery of a wheel which is advanced at intervals. The pins are then completed in the heading machine (**227**).

227 Machine for Heading Pins c.1865

This is one of the machines from a workshop for making pins at Staple Hill near Bristol. Lengths of wire cut and pointed in another machine (**226**) are placed in the hopper from which the pins are taken one at a time by a wheel with grooves in its edge. As each pin is brought to the working position it is gripped at the pointed end by a chuck and at the other end by the two halves of a die into which a punch enters to form the head. It is then released. The motions are derived from four cams on the main shaft.

Portraits, etc.

See also **206**

228 Wilkinson Tokens 1787-90

Tokens are coins which were formerly issued by employers of labour in connection with the truck-shop system and to remedy the scarcity of small coin. These tokens were issued by John Wilkinson, 1728-1808. The obverses of tokens i to iv show the portrait bust of Wilkinson and are inscribed JOHN WILKINSON IRONMASTER. The edges are inscribed BERSHAM BRADLEY WILLEY SNEDSHILL. Reverses show: (i) A sailing ship, 1788; (ii) A forge with tilt hammer, 1790; (iii) Vulcan at the forge. Halfpenny, 1791; (iv) Forge, 1787. (v) Obverse: Portrait bust of Wilkinson—Inscription JOHN WILKISON (Sic) IRON MASTER. Reverse: Forge (as ii), 1787. Edge: LONDON LIVERPOOL ANGLESEY.

229 Henry Maudslay 1771-1831

Plaster cast of the original marble bust by Sir F. Chantrey.

230 Benjamin Cheverton 1794-1876

Portrait bust in plaster. Cheverton was an engraver and the inventor of a successful sculpture copying machine (**205**).

231 Richard Roberts 1789-1864

Water colour miniature by Alfred Bradshaw. 5½ in by 4½ in.

232 Richard Roberts 1789-1864

Photograph 3½ in by 2¼ in.

233 Richard Roberts 1789-1864

Membership diploma of the Literary and Philosophical Society of Manchester. Dated April 18th, 1823. Signed by John Dalton, President.

234 James Nasmyth 1808-1890

Miniature portrait of Nasmyth as a young man. Oval 3½ in by 2¾ in.

235 Sir Joseph Whitworth 1803-1887

Portrait in oils dated June 19, 1846. 29 in by 24 in.

Miscellaneous

236 Model of File-cutting Machine

This model follows Leonardo da Vinci's design in the Codice Atlantico, folio 6 R.b, which was written between 1483 and 1518. It represents an automatic machine driven by the fall of a weight hanging from a cord which passes over a pulley and is wound onto a windlass, which is part of the main shaft of the machine. The shaft drives a tilt-hammer and, also, through a lantern gear, crown wheel, and lead-screw, causes the carriage to traverse, so that the file-blank clamped to the carriage is moved relatively to the hammer between blows. The hammer has a chisel edge, so that in the traverse of the carriage the blank receives a succession of cuts from end to end.

The drawing shows three hammer heads: two with oppositely inclined edges for making single-cut and double-cut files, and a third suitable for cutting a rasp for working in horn.

237 Drawings from the Goodrich Collection

The papers left by Simon Goodrich, 1773-1847, engineer and mechanist to the Navy Board, include several drawings of machine tools. These include three drawings of Dunsterville's block factory and machinery at Plymouth, 1802; three drawings of Sir Samuel Bentham's circular-saw benches, 1796-1800; a design for a perpendicular power hammer, 1812; two drawings of tilt and lift hammers, 1805 (see **8**); a drawing of the Portsmouth iron and copper mill.

A complete list was published in the *Transactions of the Newcomen Society*, Vol XIX, 1938-1939, pp 249-265.

238 Drawings of Machine Tools by Joshua Buckton & Co, Leeds 1840-1851

Twenty-eight tinted drawings, 21 in by 15 in, of machine tools including machines for cutting wheels, punching and shearing, planing, screwing, boring, and drilling; hydraulic wheel press; various lathes; scroll chuck; and special machines used for the manufacture of textile machinery, ie for drilling and tapping fallers, bending flyers, fluting rollers, cutting flyer bosses and ends.

239 Model of an Engineering Workshop

Scale 1 : 12. (*See plate 16*)

This working model, which was made by William Austen between 1849 and 1870, represents a general engineering workshop of about the middle of the nineteenth century. It shows the stage in development of machine tools reached at that time. In order to keep the model within practicable dimensions, however, the machines have been more crowded than would be efficient in the handling of work of such a size as the capacities of the various tools indicate. The tools are belt driven from overhead line shafts which are driven by a table engine (patented by Henry Maudslay in 1807 and popular for many years afterwards) at one end of the shop, the boiler end and the steam pipes being indicated. At the other end of the shop is the foreman's office.

The items shewn are as follows: (1) a tool store; (2) a plain horizontal milling machine; (3) a grindstone; (4) and (5) slide-rest lathes; (6) a small screw-cutting lathe; (7) a large screw-cutting lathe; (8) a gap lathe for handling large circular work such as wheels, cylinder covers, etc; (9) a wheel lathe for similar duty; (10) a small centre lathe; (11) a plain milling machine, similar to the nut-milling machine invented by Nasmyth in 1829; (12) a vertical drilling machine; (13) a shaping machine; (14) a small table planer of unusual type, being driven by a horizontal crank and connecting rod; (15) a screwing machine for pipes, etc; (16) a second vertical drilling machine; (17) a small plain lathe; (18) another screwing machine; (19) a fitters' bench; (20) a plain lathe; (21) double grindstones; (22) the foreman's office; (23) and (24) two plane marking-out tables; (25) a fitting bench with 14 vices; (26) a vertical slotting machine; (27) a vertical boring machine set for boring a cylinder cover, the table being arranged to move sideways to leave the space beneath the spindle free to receive large objects such as cylinders; (28) a large table planer; (29) a power-driven shearing and punching machine; (30) a blacksmith's hearth and anvil; (31) a gap lathe; (32) a wheel lathe; (33) a large screw-cutting lathe; (34), (35), (36), and (37) four slide-rest lathes; (38) a grindstone; (39) a carpenter's bench; (40) a circular saw bench of simple type with wooden table; (41) a planing machine; (42) a vertical slotting machine; (43) a small plain lathe; (44) a fitter's bench; (45) a small planing machine; (46) a shaping machine set up for gear cutting; (47) a vertical drilling machine; (48) a plain milling machine.

240 Engraving Machine c.1869

This is a small lining machine designed by H. T. Ryall, the engraver, for filling in skies on steel or copper plates. It consists of a wooden frame, supported at the four corners so that long plates can be worked; upon the frame as a guide slides a saddle, and along the saddle slides a small carriage that carries the graver. The carriage is moved to and fro by the pull of a band moved by a pulley and winch handle at the right hand side, the carriage being kept down on its guides by the finger of the left hand. A cross-bar working in inclined slides supports the graver clear of the plate when desired. The motion of the saddle is controlled by a lever on it, which is connected to a steel strip, which works in a clamp on the frame. The clamp is tightened and the lever moved, so moving the saddle through a small distance; the clamp is then released and the lever moved back, and so on, a very fine feed being thus obtainable, and one of varying amount, as the motion of the lever is controlled by an adjustable screw.

241 Model of Machine for Cutting Mouldings

Scale 1 : 8

The model shows a machine for preparing mouldings, in which the pattern undulates slightly in two directions. The timber to be worked is secured to a sliding horizontal table, driven by a rack below it, which is advanced by a pinion worked by spur gear from a winch handle. On the winch shaft are two cams, one of which gives a vertical oscillation to the tool holder and the other a horizontal oscillation; the holder is held in compound guides secured to the main framing and has a screw for adjusting the depth of the cut. No cutter is fitted on the model, but it may have been a moulding iron the full width of the work. The exhibit includes worked specimens. The model came from the estate of Sir Charles Wheatstone (1802 – 1875).

242 Automatic Saw Sharpening Machine 1911

This is a machine for sharpening band or other similar saws by means of a circular file or fine toothed milling cutter rotated by hand.

The saw blade is mounted below the file in an adjustable clamp, and the file is made with a notch at one point on the circumference, in which is fitted a steel cam-plate that feeds the saw forward by one tooth for every revolution. Such a machine sharpens all the teeth uniformly and at the rate of about 4 ft/min.

243 Band Saw Setting Machine 1911

This is a machine for setting the teeth of band saws rapidly and accurately.

It consists of a frame in which the saw blade is held by an easily adjustable clamp so as to be free to slide endwise. To this frame is pivoted a lever which is oscillated by hand in a direction at right angles to the saw. A steel plate is secured to the lower and shorter arm of the lever, and projections on this plate act upon the teeth of the saw and set them to one side or the other on alternate strokes of the lever. At the middle of each stroke the saw is fed forward by a pawl attached to one arm of a bell-crank lever the other arm of which is acted upon by a cam formed on the lever. The pawl is returned by a spring and its stroke is regulated by a screw. Two screws, passing through lugs on the lever boss and bearing against stops on the frame, serve to regulate the amount of set.

244 Die Casting Machine 1938

This small machine, made by R. P. Bannerman & Son, London, is suitable for hand or power operation. It will cast small objects such as clockwork pinion wheels at the rate of some thousands per hour. The metal used is an alloy of lead and antimony with a small quantity of tin.

245 Broaches

Broaching is the process of removing material by pushing or pulling across the surface to be machined a tool called a broach having a number of teeth or cutting edges of graded length which successively engage the work. Breaks staggered in successive teeth prevent chip crowding and reduce chip width. The last few teeth are of the exact shape required and the operation is completed in a single traverse.

Broaching enables intricate forms to be produced with great rapidity. A gear-form broach and a keyway broach together with examples of an internal gear before and after broaching and a broached lock barrel are exhibited.

The principle of broaching first occurs in a design by Leonardo da Vinci (C.A. 16 R.C) of a tool for cutting iron bars. Then, in 1729, Christopher Polhem in Sweden used broaches in a machine for cutting clock wheels. In the mid nineteenth century broaching tools called drifts were hammered or pressed through the work.

The modern use of broaching is due to J. N. Lapointe, who established a factory to make broaches and broaching machines in 1902.

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Inventory and Photograph Numbers, Donors and Lenders

Catalogue Numbers	*Inventory Numbers*	*Photograph Numbers*	*Donors and Lenders*
1	1926-622	2,888 ; 2,929	
2	1931-196	5,560	C. E. Greener
3	1937-877		E. Walker
4	1939-174		Noel Spencer
5	1952-451	827/52 ; 14/54	Lt.-Cdr. J. Holdsworth
6	1876-1257	830	Jas Watt and Co.
7	1876-1487	834	Jas Watt and Co.
8	1925-417	503/64	
9	1857-3	21736	James Nasmyth
10	1932-158		W. Sisson
11	1935-520		H.M. Office of Works
12	1933-583	523/57	D. J. Johnson
13	1957-15	692/50	
14	1905-182	3426	
15	1904-8		Peter Pilkington Ltd.
16	1891-161	19755	Messrs. B. and S. Massey
17	1906-20	3427	
18	1876-1243 1876-1244	835 ; 836 832	Jas Watt and Co.
19	1913-492, 1914-413		Alexander Reynell
20	1904-18		William Melling
21	1962-258	66/64	Deputy Master of the Royal Mint
22	1912-9, 1903-111	303	The British Mannesmann Tube Co.
23	1931-226		Messrs. W. H. A. Robertson and Son
24	1926-890	2,889	
25	1900-24		
26	1861-52		G. B. Thorneycroft
27	1962-259		Deputy Master of the Royal Mint
28	1912-81	348	
29	1912-82	31,773	
30	1924-778		The Selson Engineering Co. Ltd.
31	1925-575		James Bennie and Sons, Ltd.

Catalogue Numbers	*Inventory Numbers*	*Photograph Numbers*	*Donors and Lenders*
32	1929-1042	201/63	J. B. Stone and Co. Ltd.
33	1904-19		William Melling
34	1857-4	19,746	W. Ryder
35	1924-527		Ryder and Son, Ltd.
36	1910-22		
37	1931-863	6,392	J. Brownlie
38	1891-150		Messrs. F. and T. Affleck
39	1935-528		Professor James Greig
40	1895-63	19,753	R. H. Tweddell
41	1907-25		Weldless Chains Ltd.
42	1919-228		W. Kennedy
43	1962-222, -223		Exors of F. W. Hentsch
44	1908-16		
45	1912-49		
46	1938-655		Sweeney and Blocksidge (Power Presses) Ltd.
47	1938-656		Sweeney and Blocksidge (Power Presses) Ltd.
48	1931-783	31/55	
49	1904-15	30,899	
50	1947-243		Holden and Hunt Ltd.
51	1912-74 1922-686 1925-97	1272 8,318	H. V. Bullbrook Rev. J. E. Shephard
52	1939-344	375/60	
53	1955-281	375/60	E. J. Jordan
54	1907-20	185	Thos. Noakes and Sons Ltd.
55	1953-347		
56	1949-347	423/51; 424/51; 381/50; 385/50	A. H. Joice
57	1935-634	139/39	Sannyer Atkin
58	1912-53 1913-486	446; 6,504 (headstock)	
59	1888-393	24,699; 21,740 (detail)	
60	1912-281, -282	1,630; 258/55 (separate headstock)	Miss Prescott
61	1925-776	2,931	
62	1946-167		Dr. W. L. Hildburgh
63	1963-120	724/50	
64	1939-55		Professor D. S. Torrens

Catalogue Numbers	*Inventory Numbers*	*Photograph Numbers*	*Donors and Lenders*
65	1937-185	90/56	Dr. W. L. Hildburgh
66	1938-15		F. G. Rendall
67	1925-779		
68	1934-439		H. G. Hicks
69	1910-13	222	
70	1920-638 to -644	257/55 ; 260/55	
71	1900-20	26,159 ; 463/62	
72	1900-19	26,160 ; 792/53	
73	1922-543, -544	2,244 ; 2,253 (headstock) ; 822/64 (eccentric chuck)	
74	1909-65	703/56 ; 198 ; 177/64 (back gearing)	Beyer, Peacock and Co. Ltd.
75	1937-121	140/39	
76	1878-89	20,520	Maj.-Gen. H. P. Babbage
77	1891-143	20,644	Messrs. Bullivant and Co.
78	1951-249	855/55	University of Manchester
79	1948-145		George Wailes and Co. Ltd.
80	1857-9		R. Bodmer
81	1910-14		
82	1868-257, -258		
83	1957-4		Family of George Bissell
84	1928-1041		John Marston Ltd.
85	1947-213		Dowding and Doll Ltd.
86	1963-121		Messrs. W. A. Fowler and Co.
87	1956-105, -106	558/61 (chuck)	C. T. Wooler (Engineers) Ltd.
88	1897-59, 1899-72	19,620	Smith and Coventry Ltd.
89	1904-17 1904-118, -119, 1912-351-352, 356	31,094	
90	1960-218		A. Freeman
91	1910-15	235	
92	1911-96	845 ; 846 (lathe) ; 561/61 ; 562/61 (work)	Exors of H. C. Robinson

Catalogue Numbers	*Inventory Numbers*	*Photograph Numbers*	*Donors and Lenders*
93	1952-453, 1953-176		Dorset County Museum R. P. Howgrave-Graham
94	1931-518		T. Toledano
95	1933-518		J. Smith & Co.
96	1938-115	138/39	
97	1938-643	138/39	
98	1912-35	559/61	
99	1920-643	560/61	
100	1910-12		
101	1910-11	5,931	
102	1912-50		
103	1912-52		
104	1912-51		
105	1913-23		
106	1928-291		G. M. Grace
107	1912-34	641/64	
108	1912-36	642/64	
109	1928-1162, 1930-395	563/61 to 571/61; 507/64 to 510/64	Holtzapffel and Co. Ltd.
110	1930-375		G. Baillie
111	1938-171		HM Queen Mary
112	1945-95		Miss Kerr-Sander
113	1920-644		
114	1960-73		Saunderson and Costin, Ltd.
115	1892-105		Messrs. H. B. Barlow and Co.
116	1887-111		The Brittania Co.
117	1887-115		Messrs. Wellington and Co.
118	1907-7		
119	1912-69		H. M. Budgett
120	1919-259		H. M. Budgett
121	1920-672		Wearden and Guylee Ltd.
122	1921-308		Charles Taylor (Birmingham) Ltd.
123	1954-81		Lenchs (Birmingham) Ltd.
124	1952-281	878/52	
125	1900-21	26,314	
126	1948-315		John Watney and Co. Ltd.
127	1860-54, -55	20,888	Mr. Elliott

Catalogue Numbers	*Inventory Numbers*	*Photograph Numbers*	*Donors and Lenders*
128	1861-51		W. E. Newton
129	1908-22	237	
130	1920-634, -635		Alfred Herbert Ltd.
131	1920-657, -658		Alfred Herbert Ltd.
132	1923-15		Alfred Herbert Ltd.
133	1928-1045		John Holroyd and Co. Ltd.
134	1934-82		The National Physical Laboratory
135	1959-288		Saunderson and Costin Ltd.
136	1952-282	879/52	
137	1923-303	3,684	
138	1930-187	4,395	
139	1927-985	3,442; 3,443	
140	1913-172		The Hydraulic Engineering Co. Ltd.
141	1920-98	1,327	
142	1960-226	734/60	
143	1954-639		English Sewing Cotton Co. Ltd.
144	1945-1		H. J. Latham
145	1899-9	20,641	
146	1931-195		John Bradley and Co. (Stourbridge) Ltd.
147	1860-45	19,742	Richard Roberts
148	1868-21, 1862-118	19,747	The Institution of Civil Engineers
149	1910-16		
150	1912-60		Vickers Ltd.
151	1961-129	65/64	The War Office
152	1920-636		The Oliver Machinery Co. Ltd.
153	1925-31		Frederick Pollard and Co. Ltd.
154	1957-97		Mullard Ltd.
155	1860-59	20,695	Richard Roberts
156	1908-20	238	
157	1899-7	20,643	
158	1860-47, -48		Richard Roberts
159	1938-332		
160	1899-8	20,642	
161	1926-847		
162	1860-56	140/37	Messrs. M. and J. H. Buck
163	1928-1082	137/39	

Catalogue Numbers	*Inventory Numbers*	*Photograph Numbers*	*Donors and Lenders*
164	1911-95		Hans Renold Ltd.
165	1928-1130		The Brown and Sharpe Manufacturing Co.
166	1928-1161		Holtzapffel and Co. Ltd.
167	1961-56	500/61; 501/61	The Singer Manufacturing Co. Ltd.
168	1921-268		Messrs. Clarke and Son
169	1928-1337, -1338		Thomas Robinson and Son, Ltd.
170	1954-421	719/55; 720/55 (Underside)	
171	1905-13	3,647	The Lancashire Watch Co. Ltd.
172	1900-6	21,753	
173	1963-32		A. A. Osbourne and Son, Ltd.
174	1960-238		J. L. Charlton
175	1857-5	721/50	R. Bodmer
176	1857-6	723/50	R. Bodmer
177	1947-18		George Wailes and Co. Ltd.
178	1928-1131		The Brown and Sharpe Manufacturing Co.
179	1950-113		Alfred Herbert Ltd.
180	1922-25, 1924-673	3,648; 3,649	Robey and Co. Ltd. Smith and Coventry Ltd.
181	1964-120		
182	1928-1219		George Wailes and Co. Ltd.
183	1922-138		Chas. R. Turner
184	1910-9		C. K. Eley
185	1858-12	623	W. Muir and Co.
186	1866-60		D. Fisher
187	1962-229		Ormonde Ashton Ltd.
188	1936-87		The National Physical Laboratory
189	1912-33		
190	1912-65		Messrs. Geo. W. Goodchild and Partner
191	1899-119		
192	1859-1	20,522	Lady Bentham
193	1859-2, -3		Lady Bentham
194	1864-47	875/57	S. Worssam and Co.
195	1888-253	136/39	J. Barr
196	1892-100	19,757	
197	1902-5	30,896	
198	1894-168		Messrs R. Garrett and Sons

Catalogue Numbers	*Inventory Numbers*	*Photograph Numbers*	*Donors and Lenders*
199	1902-10	1,266	M. Glover and Co.
200	1925-687		Thomas Robinson and Son, Ltd.
201	1935-25		Edward G. Herbert Ltd.
202	1922-265	3,644; 3,645	A. C. Jackson
203	1924-792	2,395	Major J. M. Gibson-Watt
204	1924-792	2.394	Major J. M. Gibson-Watt
205	1924-292	3,650	
206	1947-12		Messrs. Groves and Co.
207	1910-1	254	Deputy Master of the Royal Mint
208	1910-2	255	Deputy Master of the Royal Mint
209	1892-96	19,618	
210	1931-718		A. Lambourne
211	1935-130	874/57	Messrs. Bramah
212	1935-131		Messrs. Bramah
213	1935-130		Messrs. Bramah
214	1935-128	305/38	Messrs. Bramah
215	1935-129	306/38	Messrs. Bramah
216	1948-193	107/63 to 109/63	The Admiralty
217	1949-256		The Admiralty
218	1948-142	665/50	The Admiralty
219	1948-141	664/50	The Admiralty
220	1948-140	662/50; 663/50	The Admiralty
221	1951-571	55/55	The Admiralty
222	1948-138		The Admiralty
223	1948-139	660/50; 661/50	The Admiralty
224	1933-133	303/38; 304/38	The Admiralty
225	1957-1	603/59	The War Office
226	1937-886		
227	1937-887		
228	1938-586		W. H. Wilkinson B. W. Doncaster
229	1857-306	663	J. Maudslay
230	1924-293	572/61	
231	1917-6		A. Luboldt
232	1917-8		A. Luboldt
233	1917-7		A. Luboldt

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234	1952-239	1,233/52	
235	1903-176	140/56	Woodcroft Bequest
236	1952-280	880/52	
237	1875-43, -44, -46, -50		Mrs. S. Goodrich
238	1921-445	4,027 to 4,031	Craven Bros. (Manchester) Ltd.
239	1927-1051	374/51	
240	1896-106		Mrs. H. T. Ryall
241	1876-1234	19,615	Exor of Sir Charles Wheatstone
242	1911-68		M. Glover and Co.
243	1911-69		M. Glover and Co.
244	1938-439		H. Pearce
245	1962-366 to -370		The Lapointe Machine Tool Co. Ltd.

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